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# Design of Surface Mine Haulage Roads—A Manual

UNITED STATES DEPARTMENT OF THE INTERIOR

Information Circular 8758

# Design of Surface Mine Haulage Roads—A Manual

By Walter W. Kaufman and James C. Ault

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CONTENTS

## ILLUSTRATIONS



## TABLES

# DESIGN OF SURFACE MINE HAULAGE ROADS—A MANUAL

by

Walter W. Kaufman [1] and James C. Ault[2]

ABSTRACT

This Bureau of Mines manual for design of surface mine haulage roads covers such aspects of haulage road design as road alinement (both vertical and horizontal), construction materials, cross slope, and drainage provisions. Traffic control and design of proper lane widths to promote safe vehicle movement are included, as are suggested criteria for road and vehicle maintenance and for runaway-vehicle safety provisions. The aim of this publication is to provide those involved with surface mine haulage road design with a complete manual of recommended practices that, if implemented, will promote safer, more efficient haulage routes.

## INTRODUCTION

During the past 30 years, surface mine haulage equipment has developed from trucks capable of moving 20 tons of material to vehicles that transport as much as 350 tons. Unfortunately, the design of roads this equipment must traverse has not advanced at the same rate. In many areas, road building technology appropriate to vehicles of three decades past is still being practiced today. As a result, numerous unnecessary haulage-road accidents have occurred every year. A number of these mishaps can be attributed to operator error. However, far too many are caused by road conditions that are beyond the vehicle's ability to negotiate safely. With this history of haulage-related problems in mind, the Bureau of Mines undertook a project to produce a design manual that would ultimately guide surface mine road planners toward safer, more efficient haulage systems. Such a manual did not exist prior to the conclusion of this project. This manual was produced under a contract let by the Bureau of Mines to Skelly and Loy Engineers and Consultants.

Information relating to the content of the manual was gathered through contacts with mining companies and equipment manufacturers across the country. Review of mining practices in some foreign countries also provided input. Literature sources relevant to good road design methods were reviewed and listed where appropriate in the text.

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It is the purpose of this document to identify the performance limitations of modern haulage equipment and to examine the impact of haulage road design on vehicular controllability. Based on these evaluations, haulage road design criteria that will promote continuity and safety throughout the haulage cycle were established.

Time allocated for this project prohibited a detailed investigation of mechanical design for every type of haulage road user. However, safe road design criteria should be sufficiently comprehensive to allow application to all machine types.

This complication required that design criteria be based on the one type of surface mining equipment that exhibits the lowest safety potential. Research of engineering data for all major types of surface mine machinery revealed that large off-the-road haulage trucks had the smallest margin of safety due to their great size and weight, characteristic use, and control components. Thus, designing haulage roads to accommodate these vehicles leaves a wide margin of safety for all other surface mining equipment.

Extensive engineering data for all makes and models of large off-the-road haulage vehicles was solicited from manufacturers. Information was tabulated to identify specifications for width, height, weight, tire track, wheel base, type of braking system, steering ability, retarder performance, speed and range on grade, and numerous other factors for each truck model. Various models were then grouped into four weight-range categories, and minimum, mean, and average specifications were identified for each weight category.

Design guidelines for each weight category, including velocity-stopping distance curves, vertical curve controls, haulageway widths, curve widening, and spacing of runaway devices, are presented in this report.

The haulageway designer may utilize the Contents section of this report as a checklist to assure that all elements of design have been considered in planning the haulage road.

## HAULAGE ROAD ALINEMENT

As far as is economically feasible, all geometric elements of haulage roads should be designed to provide safe, efficient travel at normal operating speeds. The ability of the vehicle operator to see ahead a distance equal to or greater than the stopping distance required is the primary consideration. This section of the study addresses the effect of speed, slope, and vehicle weight on stopping distance, as well as design criteria for vertical and horizontal alinement.

### Stopping Distance--Grade and Brake Relationships

From a safety standpoint, haulage road grades must be designed to accommodate the braking capabilities of those vehicles having the least braking potential which will most frequently traverse the haul route. In the majority of cases, rear, bottom, and side dump trucks, by virtue of their function

within the mining operation, are the most frequent haulage road users. Due to their extreme weight and normally high operating speeds in relation to other equipment, their ability to decelerate by braking is lowest of the constant haulage road users. The design of routes that accommodate the braking systems of haulage trucks should leave a sufficient margin of safety for other equipment less frequently used, such as dozers, loaders, scrapers, graders, etc.

Most truck manufacturers' specifications for brake performance are limited to an illustration of the speed that can be maintained on a downgrade through use of dynamic or hydraulic retardation. Although retardation through the drive components is an efficient method of controlling descent speed, it does not replace effective service brakes. In the event of retardation system failure, wheel brakes become the deciding factor between a halted or runaway vehicle.

Unfortunately, very few, if any, truck manufacturers define the capabilities of their service and emergency braking systems in terms of performance. They are usually described by lining area, drum or disk size, method of actuation, and system pressure. Thus, an operator does not know whether the brakes of the vehicle will hold on a descent grade in the event of a retardation failure. Because of the possible need to utilize service brakes as the sole means of halting or slowing a truck, their performance must be defined and taken into consideration in the design of safe haulage road grades.

The Society of Automotive Engineers (SAE), realizing the need for effective brake performance standards, has developed test procedures and minimum stopping distance criteria for several weight categories of large, off-highway trucks. SAE-recommended practice J166 delineates the following values as maximum permissible service brake stopping distances from an initial velocity of 20 mph, on a dry, level, clean concrete surface:

| Vehicle weight, pounds | Service brake maximum stopping distance at 20 mph, feet |
|---|---|
| <100,000 (category 1).............. | 60 |
| 100,000 to 200,000 (category 2)..... | 90 |
| >200,000 to 400,000 (category 3).... | 125 |
| >400,000 (category 4).............. | 175 |

While the majority of haulage truck manufacturers equip their products with brake systems that meet or exceed these criteria, there is no indication of how brake performance may vary with changes in grade, road surface, or initial speed. However, the stopping-distance limitations set forth provide the basic data from which performance under different conditions may be mathematically deduced.

The stopping distance curves (figs. 1-4) depict stopping distances computed for various grades and speeds in each SAE test weight category. The points for each of the various curves have been derived using the formula

$$SD = [1/2\ gt^2 \cdot \sin\theta + V_o t] + \left[\frac{(gt \sin\theta + Vo)^2}{2g(u\ min - \sin\theta)}\right], \quad (1)$$

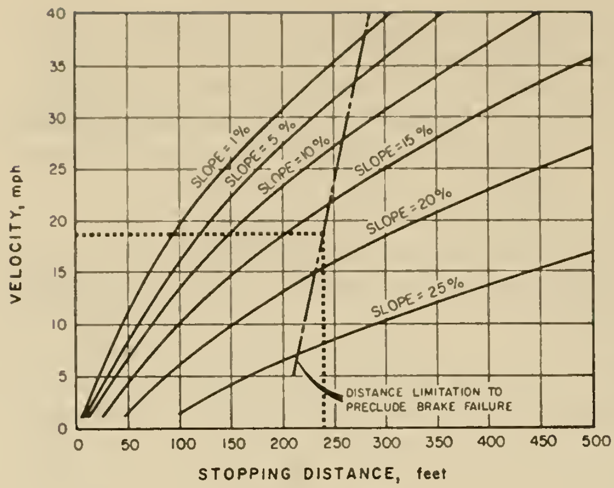


FIGURE 1. - Stopping distance characteristics of vehicles of less than 100,000 pounds GVW.

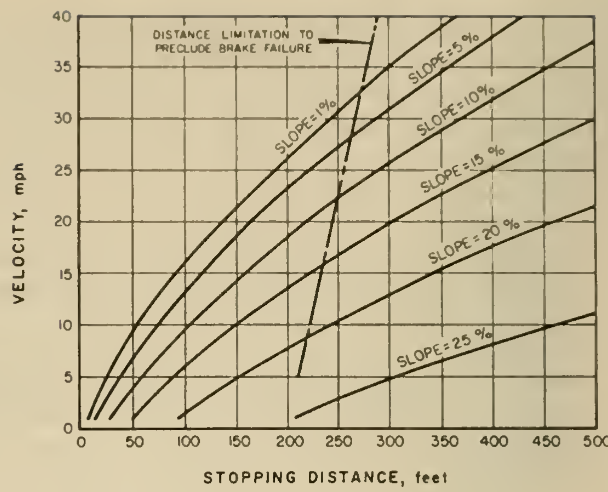


FIGURE 2. - Stopping distance characteristics of vehicles of 100,000 to 200,000 pounds GVW.

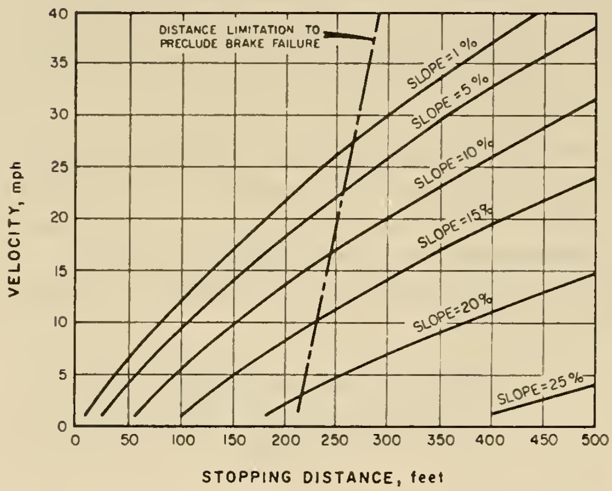


FIGURE 3. - Stopping distance characteristics of vehicles of 200,000 to 400,000 pounds GVW.

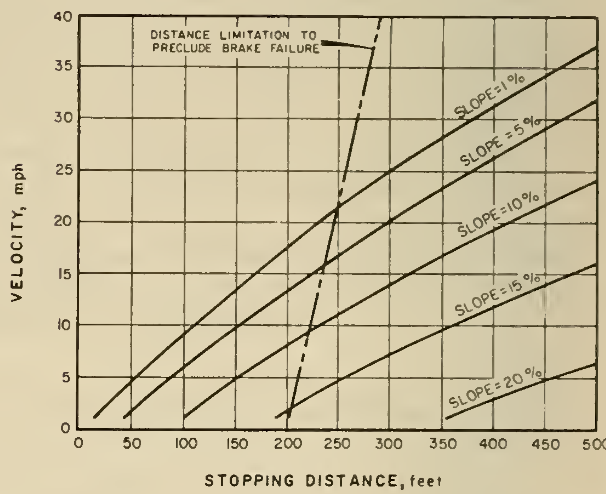


FIGURE 4. - Stopping distance characteristics of vehicles of greater than 400,000 pounds GVW.

where $SD$ = stopping distance, feet,

$g$ = gravitational pull (32.2 $fps^2$),

$t$ = time expended between driver's perception of the need to stop and the actual occurrence of frictional contact at the wheel brakes, seconds,

$\theta$ = angle of descent, degrees,

$V_o$ = speed at time of perception, feet per second,

and $u\ min$ = coefficient of friction at the tire-road contact area, dimensionless.

Although the significance of SAE stopping distances is not readily apparent in equation 1, it was the means of arriving at u min and t values.

The t value is actually composed of two separate time intervals, $t_1$ and $t_2$.

The time necessary for pressure to build and actuate brake components after the pedal is depressed in the cab is designated $t_1$. Information supplied by a member of SAE subcommittee 10 (the authors of J166) gives the following as values for $t_1$. These numbers have been verified by various subcommittee members and their companies.

| Vehicle weight, pounds | Brake reaction time ($t_1$), seconds |
|---|---|
| <100,000 | 0.5 |
| 100,000 to 200,000 | 1.5 |
| >200,000 to 400,000 | 2.75 |
| >400,000 | 4.5 |

A second component of t, designated $t_2$, is the lag attributed to driver perception and reaction, or the time lost from the instant an operator sees a hazard until his foot actually begins depressing the brake pedal. A time of 1.5 seconds[3] was assigned for $t_2$ in all cases.

A value for u min, the coefficient of friction achievable at the tire and ground interface, is found using the formula

$$u\ min = \frac{V^2}{2gS}, \tag{2}$$

[3]American Association of Highway Officials. A Policy on Geometric Design of Rural Highways. Association General Offices, Washington, D.C., 1965, 311 pp.

where $V$ = SAE test velocity of 29.33 fps,

$g$ = gravitational pull of 32.2 fps$^2$,

and $S$ = SAE actual braked distance (computed by subtracting $t_1 \times 29.33$ from the SAE recommended stopping distance for each weight classification).

In all cases, the equation computes to a coefficient of friction (u min) averaging 0.30 and a vehicular deceleration of approximately 9.66 fps$^2$.

With the t and u min values identified, it is possible to use equation 1 and arrive at values illustrated in the stopping-distance curves for different grade-speed operating conditions. This formula, however, does not allow a determination of the distance at which constant brake application will result in excessive heat buildup and, consequently, cause fade or complete brake failure.

Since it is unrealistic to assume that brakes can remain applied without fade for excessive periods of time, heat buildup must be considered. Unfortunately, factors influencing the ability of a brake system to dissipate heat vary to such an extent that accurate mathematic simulation is virtually impossible. In fact, there appears to be no definite conclusion as to the maximum temperature a brake system can withstand before negative effects are noticed. The obvious need to limit stopping distances to prevent excessive brake heat, combined with the inability to realistically simulate thermal characteristics, presented a problem.

Resolution of this difficulty was achieved through the acceptance of empirical test data from the British Columbia Department of Mines and Petroleum Resources.[4] This organization has conducted more than 1,000 haulage truck stopping-distance tests at active mine sites in British Columbia. The variety of truck makes and models included in the testing program present a representative brake performance cross section for many of the vehicles currently marketed.

Information supplied by V. E. Dawson, who coordinated this testing, indicated that to preclude fade, a 200-foot braking distance should be considered the maximum allowable. Although some tested vehicles were able to exceed this limitation and still execute a safe, controlled stop, statistics indicate that a 200-foot restriction permits a reasonable margin of safety. Each stopping-distance graph illustrates this 200-foot maximum braking distance as a vertical line increasing with velocity. Increases of distance for speed reflect footage consumed by driver perception and reaction time, factors not considered during actual tests.

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[4]Dawson, V. E. Observations Concerning On-Site Brake Testing of Large Mining Trucks. Pres. at Earthmoving Industry Conf., Central Illinois Sec., SAE, Warrendale, Pa. Apr. 15-16, 1975, 33 pp.

Inclusion of this stopping-distance restriction completes the stopping-distance graphs. Maximum operating speed and descent grade can be found for a known truck weight by reading vertically along the maximum permissible stopping-distance limitation line. At grade curve intersections, read left to find velocity. An example is given on the graph for less than 100,000-pound trucks (fig. 1).

Figures 1 through 4 have been based primarily on mathematic derivations. They do not depict results of actual field tests, but are presented simply to offer an indication of the speed and grade limitations that must be considered in designing a haulage road for a general truck size. Actual field testing has proven that many haulage vehicles can and do exceed theoretical capabilities. This empirical data, however, does not encompass a wide range of speed and grade situations. Therefore, use of this information would not permit sufficient design flexibility.

It is recommended that the operational limitations depicted in these illustrations be used to make general determinations in the preliminary planning stage of design. Before actual road layout begins, manufacturers of the vehicles that will ultimately use the road should be contacted to verify the service brake performance capabilities of their products. In all cases, verification should reflect the capabilities of wheel brake components without the assist of dynamic or hydraulic retardation.

The discontinuity between theoretical and empirical results substantiates the need for intensive and comprehensive brake evaluation programs. With the exception of British Columbia and possibly a few manufacturers, testing has been restricted to the somewhat idealistic SAE procedures. It is anticipated that continuing demands for larger equipment and the increasing safety consciousness of mine operators and employees will eventually make intensive testing programs a reality.

## Sight Distance

Sight distance is defined as "the extent of peripheral area visible to the vehicle operator." It is imperative that sight distance be sufficient to enable a vehicle traveling at a given speed to stop before reaching a hazard. The distance measured from the driver's eye to the hazard ahead must always equal or exceed the required stopping distance.

On vertical curve crests, the sight distance is limited by the road surface. Figure 5, case A, illustrates an unsafe condition. The sight distance is restricted by the short vertical curve and the vehicle cannot be stopped in time to avoid the hazard. Case B shows a remedy to the dangerous condition. The vertical curve has been lengthened, thus creating a sight distance equal to the required stopping distance.

On horizontal curves, the sight distance is limited by adjacent berm dikes, steep rock cuts, trees, structures, etc. Case C illustrates a horizontal curve with sight distance restricted by trees and steep side cut.

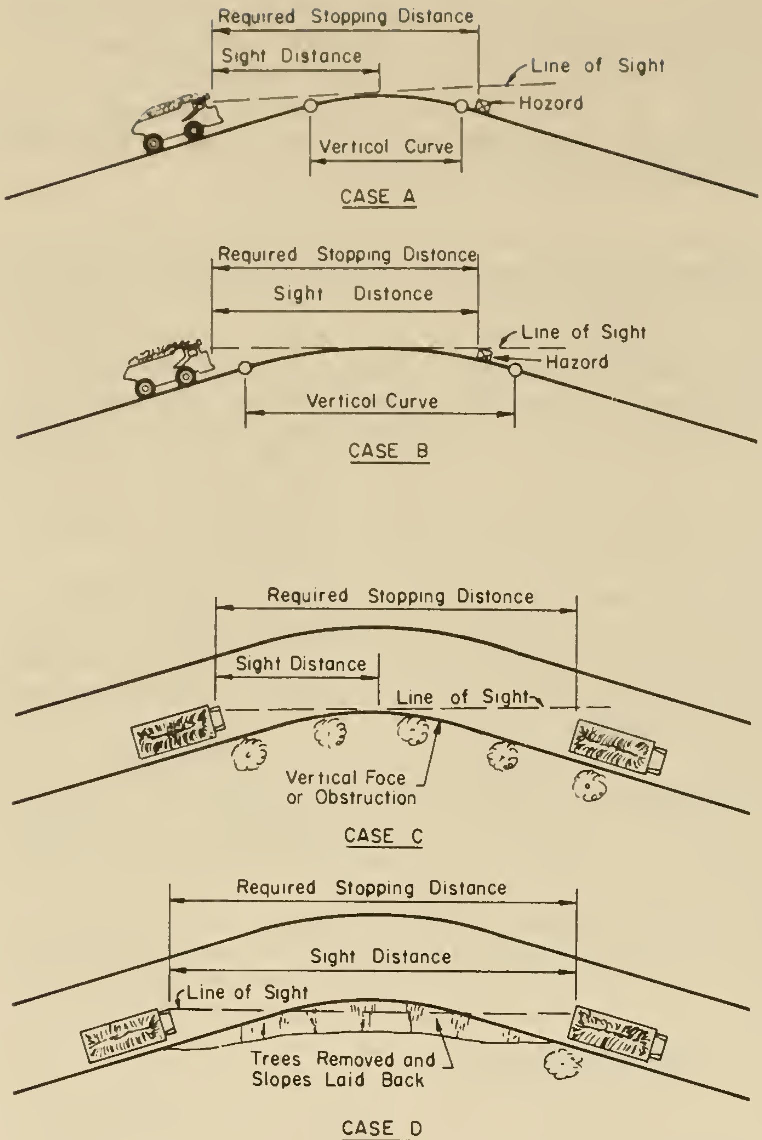



FIGURE 5. - Sight distance diagrams for horizontal and vertical curves.

Case D shows that by removing the trees and laying back the slope, the sight distance can be lengthened to equal the required stopping distance.

## Vertical Alinement

Vertical alinement is the establishment of grades and vertical curves that allow adequate stopping and sight distances on all segments of the haulage road. A safe haulage environment cannot be created if grades are designed without consideration for the braking limitations of equipment in use. The same is true for situations where hill crests in the road impede driver visibility to the point that vehicle stopping distance exceeds the length of roadway visible ahead. Design practices relevant to the foregoing parameters are presented in the following subsection.

### Maximum and Sustained Grades

Theoretical maximum allowable grades for various truck weight ranges in terms of emergency stopping situations have been defined in the stopping-distance curves (fig. 1-4). Defining maximum permissible grades in terms of stopping capabilities alone, however, is somewhat misleading in that no consideration is given to production economics. If, for example, a road were designed to include the maximum grade a truck weighing between 100,000 and 200,000 pounds (category 2) can safely descend, speed at the beginning of that grade must be reduced and sustained for the duration of descent. By the same token, ascending equipment would require frequent gear reductions and similar speed losses. This changing velocity means lost production time, additional fuel consumption, component wear, and eventually, maintenance.

Figure 6 is a performance chart similar in composition to those supplied by a majority of equipment manufacturers. Although the graph reflects performance characteristics for a specific make and model of haulage vehicle, it shows a representative impact of grade on performance. Two different symbols have been superimposed to delineate attainable speed as it is influenced by a vehicle operating on a 5% and 10% grade under loaded and unloaded conditions.

It is apparent from the chart that a reduction in grade significantly increases a vehicle's attainable uphill speed. Thus, haulage cycle times, fuel consumption, and stress on mechanical components, which results in increased maintenance, can be minimized to some extent by limiting the severity grades.

By relating the 10% to 5% grade reduction to the stopping-distance charts in the previous section, it can be seen that safety and performance are complementary rather than opposing factors. To demonstrate this fact, a reproduction of the stopping-distance chart for vehicles in the 100,000-to-200,000-pound

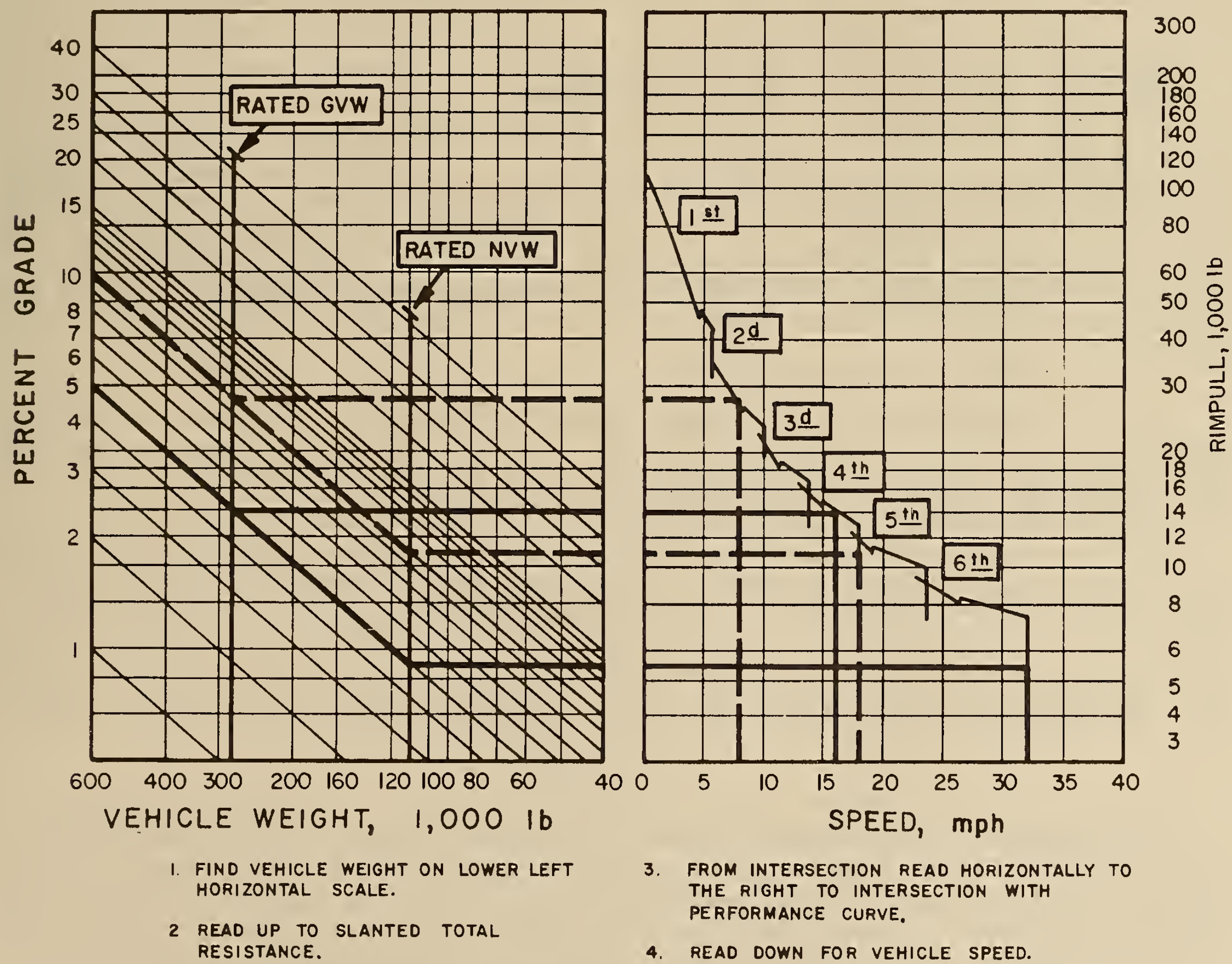



FIGURE 6. - Vehicle performance chart.

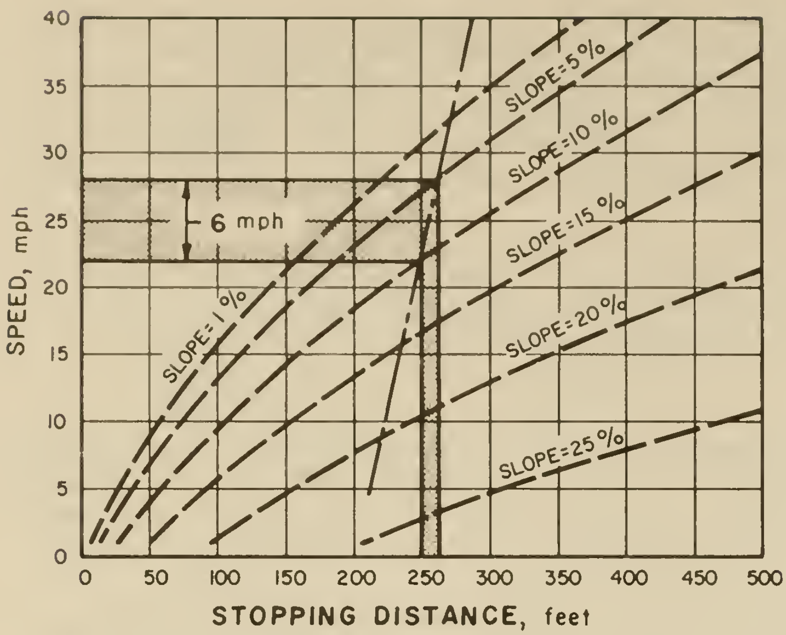



FIGURE 7. - Effect of grade reduction on stopping distances.

category is presented in figure 7 for reference. As indicated by superimposed lines on the graph, a 5% grade reduction translates to a descent speed increase of 6 mph without exceeding safe stopping-distance limitations.

The described benefits to production neglect consideration of construction economics. In the majority of cases, earthmoving to construct flatter gradients will incur greater costs. Moreover, design flexibility at many operations is curtailed by limited property ownership and physical constraints such as adverse geologic and topographic conditions. To recommend one optimum maximum grade to suit all operations, therefore, would be unfeasible. It must be the responsibility of each operator or road designer to assess the braking and performance capabilities of his particular haulage fleet and, based on this data, determine whether available capital permits construction of ideal grades or requires steeper grades at the sacrifice of haulage-cycle time.

The only guidelines that can definitely be set forth for maximum grade criteria are the laws and/or regulations currently mandated by most major mining States. Presently, a few States allow maximum grades of 20%. However, the majority of States have established 15% as the maximum grade.

Length of sustained gradients for haulage road segments are yet another factor that must be considered in vertical alinement. Many mine operators have found optimum operating conditions reflected on maximum sustained grades no greater than 7% to 9%. Also, many State laws and regulations establish 10% as a permissible maximum sustained grade. However, this does not mean that vehicles cannot be safely operated on more severe downgrades.

Significant improvements have been made in controlling downhill speed through hydraulic and dynamic retardation of drive components. Charts similar to figure 8 are available for most modern haulage equipment and illustrate their controllability on downgrades. As indicated by the example, this particular vehicle is advertised as being capable of descending a 15% grade at 8 mph if geared down to second range. Thus, the vehicle can be kept to a speed that is within the safe emergency braking limitations. The chart does not, however, specify the retardation limits in terms of time or length of sustained grade.

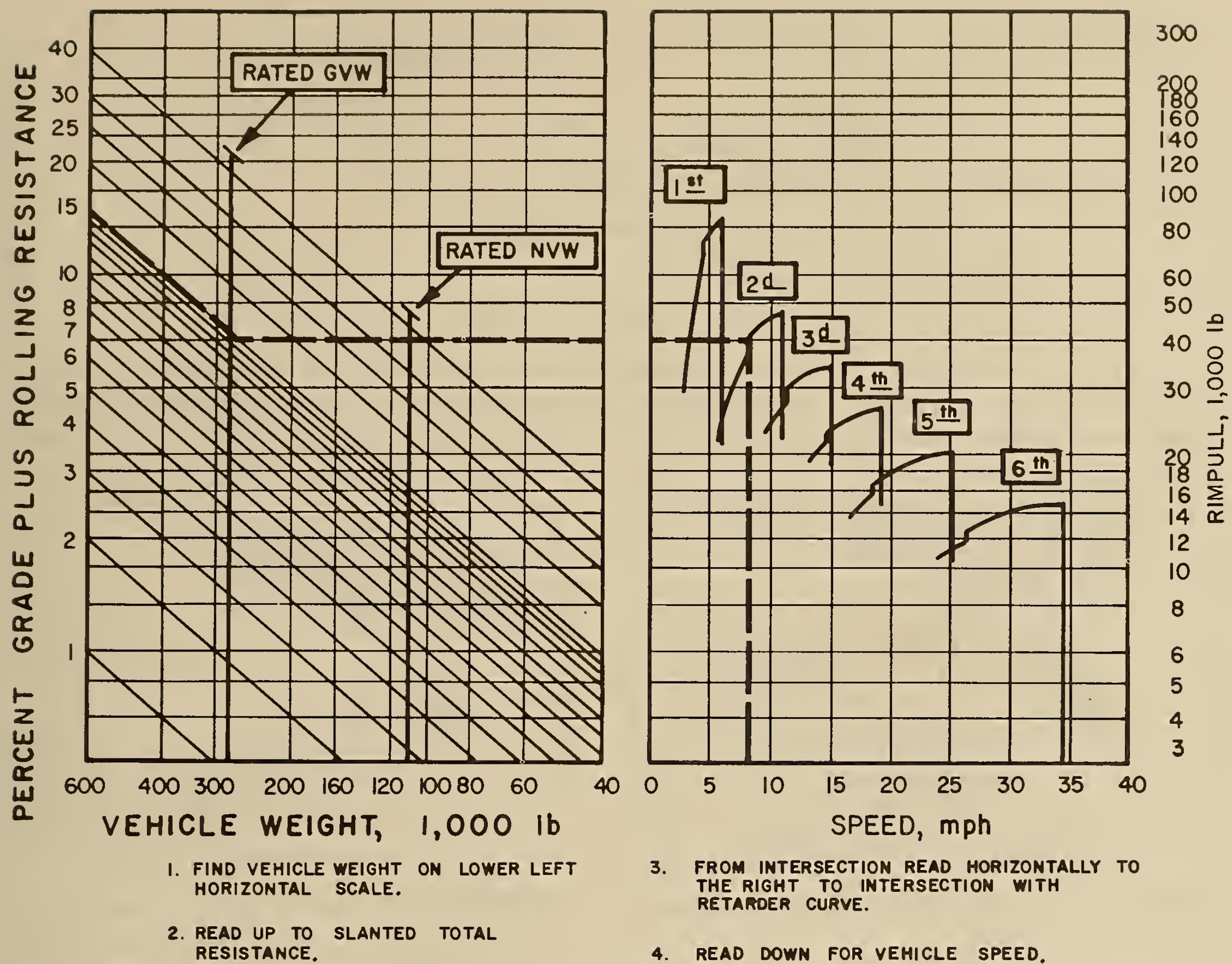



FIGURE 8. - Vehicle retarder chart.

All retardation systems function by dissipating the energy developed during descent in the form of heat. In hydraulic systems, this is accomplished through water-cooled radiators; the dynamic method generally relies on air-cooled resistance banks. It is possible to overheat either system if the combination of grade and length is excessive.

Considering the foregoing factors, it is reasonable to accept 10% as maximum safe sustained grade limitation.

## Vertical Curves

Vertical curves are used to provide smooth transitions from one grade to another. Their lengths should be adequate to drive comfortably and provide ample sight distances at the design speed. Generally, vertical curve lengths greater than the minimum are desirable, and result in longer sight distances However, excessive lengths can result in long relatively flat sections, a feature that discourages good drainage and frequently leads to "soft spots" and potholes. Curve lengths necessary to provide adequate sight distance were computed as follows:

$$L = 2S - \frac{200\ (\sqrt{h_1} + \sqrt{h_2})^2}{A} \quad \text{(when S is greater than L)} \tag{3}$$

or,

$$L = \frac{AS^2}{100\ (\sqrt{2h_1} + \sqrt{2h_2})^2} \quad \text{(when S is less than L),} \tag{4}$$

where $A$ = algebraic difference in grades,

$S$ = attainable stopping distance on grade,

$h_1$ = driver's eye height,

and $h_2$ = height of object above haulage road surface.

Figures 9 through 16 show recommended minimum lengths of vertical curves versus stopping distances for various algebraic differences in grade. Each figure represents a different driver's eye height, ranging from 6 to 20 feet.

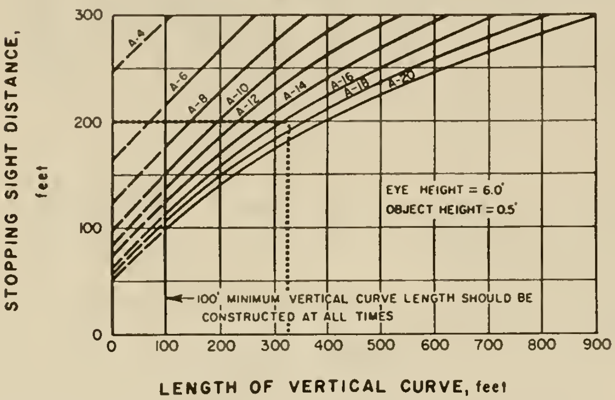



FIGURE 9. - Vertical-curve controls–6-foot eye height.

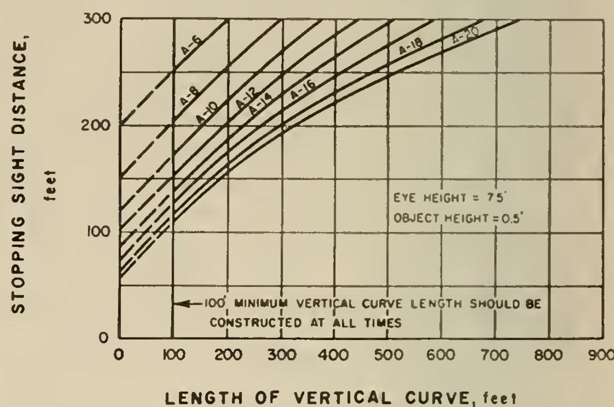



FIGURE 10. - Vertical-curve controls–7-1/2-foot eye height. This is the minimum eye height for single-unit haulage trucks of <100,000 pounds GVW.

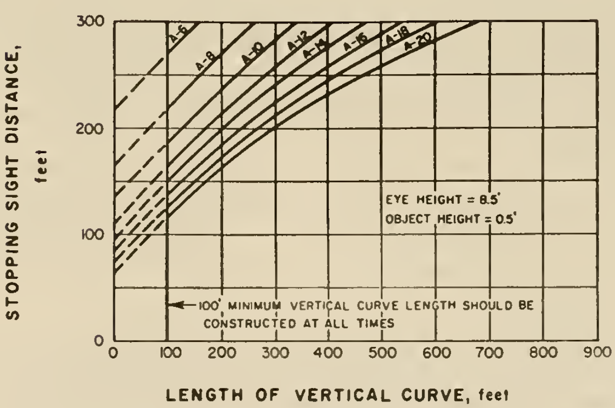



FIGURE 11. - Vertical-curve controls–8-1/2-foot eye height. This is the minimum eye height for single-unit and articulated haulage trucks of 100,000 to 200,000 pounds GVW.

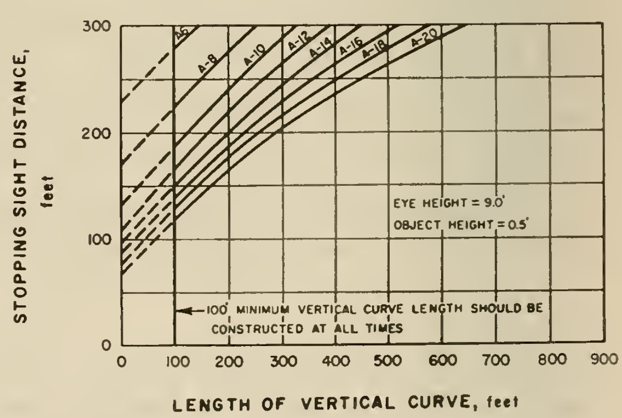



FIGURE 12. - Vertical-curve controls–9-foot eye height. This is the minimum eye height for articulated haulage trucks of >200,000 to 400,000 pounds GVW.

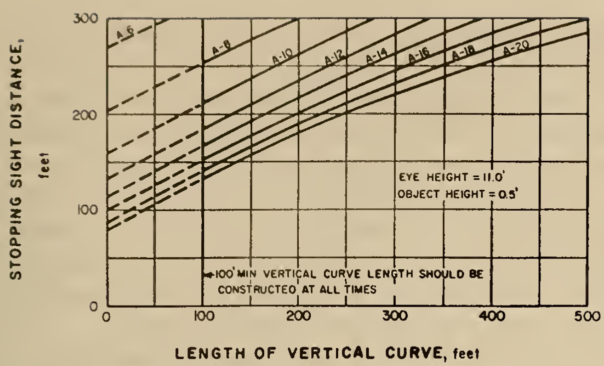



FIGURE 13. - Vertical-curve controls—11-foot eye height. This is the minimum eye height for single-unit haulage trucks of >200,000 to 400,000 pounds GVW and articulated haulage trucks of >400,000 pounds GVW.

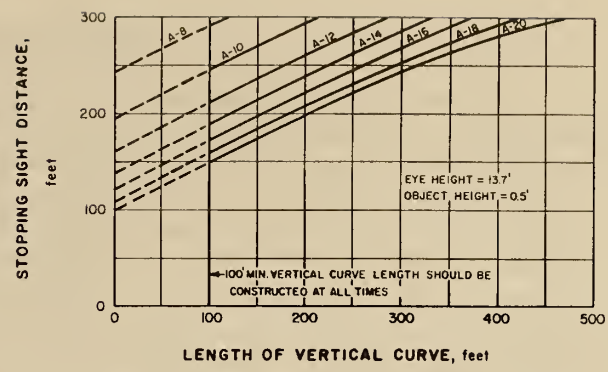



FIGURE 14. - Vertical-curve controls—13-foot 7-inch eye height. This is the minimum for single-unit haulage trucks of >400,000 pounds GVW.

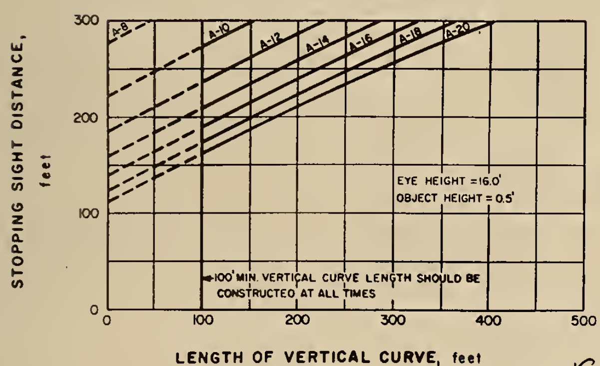



FIGURE 15. - Vertical-curve controls—16-foot eye height.

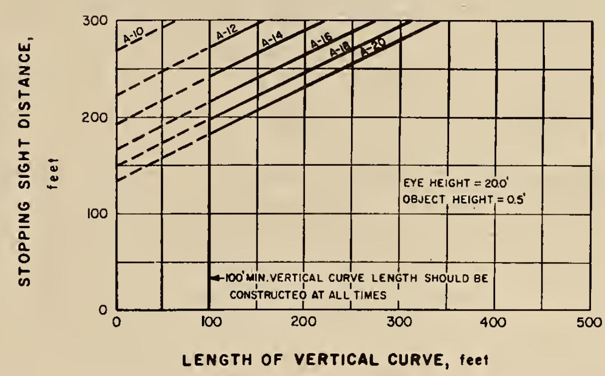



FIGURE 16. - Vertical-curve controls—20-foot eye height.

The object height used in computing crest vertical curves was 6 inches. Although there is some support for an object height equal to the vehicle taillight height, we believe the relatively small increase in vertical curve length is warranted to cover such possibilities as a prostrate figure, an animal, or dropped gear on the road surface.

To illustrate use of the vertical curve charts, first select the graph that indicates the lowest driver's eye height for vehicles in the haulage fleet. Then, from the stopping-distance charts (fig. 1-4), find the required stopping distance for the appropriate operating speed, vehicle weight, and grade. Use the steeper of the two grades to take into consideration the most critical situation. Read right to intersect the appropriate algebraic difference and down to find vertical curve length. An example is given in figure 9 for a stopping distance of 200 feet and an algebraic difference of 16 (A-16) to give a required curve length of 325 feet.

## Horizontal Alinement

Horizontal alinement during haulage road design and construction deals primarily with the elements necessary for safe vehicle operation around curves. Far too often turns are created without considering proper width, superelevation, turning radius, or sight distance. Correct horizontal alinement is essential to both safety and efficiency throughout a haulage cycle. The following subsections discuss the parameters prerequisite to correct horizontal alinement and how they affect road design. It must be emphasized that recommendations are based on the premise of providing maximum safety without taking construction economics into account. Due to the physical constraints particular to many mining sites, the cost of construction may increase significantly. Safety, however, should allow no tradeoffs, and any alterations to design criteria should be accompanied by a compensatory reduction in operating speed.

### Superelevation Rate

Vehicles negotiating short-radius curves are forced radially outward by centrifugal force. Counteracting forces are the friction between the tires and the road surface, and the vehicle weight component due to the superelevation. The basic formula is

$$e + f = \frac{V^2}{15R}, \tag{5}$$

where $e$ = superelevation rate, feet per foot;

$f$ = side friction factor;

$V$ = vehicle speed, miles per hour;

and $R$ = curve radius, feet.

Theoretically, owing to superelevation, the side friction factor would be zero when the centrifugal force is balanced by the vehicle weight component. Steering would be effortless under these conditions.

There is a practical limit to the rate of superelevation. In regions subject to snow and ice, slow-traveling vehicles could slide down the cross slope. Regions not subject to adverse weather conditions can generally have slightly higher superelevation rates. However, even in these regions, the driver of a vehicle negotiating a curve at a speed lower than the design speed would encounter some difficulty holding the proper path. He would experience an unnatural maneuver, steering up the slope, against the direction of curve.

Another consideration in establishing the cross slope rate is the high percentage of load carried by the inner wheels of a truck stopped or moving slowly on the curve.

As shown by the formula, there are two factors counteracting the centrifugal force: The superelevation rate and the side friction factor. Much

experimentation has been done to determine side friction factors. Several authorities[5] recommend a factor of 0.21 for speeds of 20 mph and less. The American Association of State Highway Officials (AASHO) has plotted the results of several studies on vehicle speeds at short-radius curve intersections. Logically, the average running speed decreased as the radius decreased. And, as the speed decreased, the side friction factor increased, producing a factor of 0.27 at 20 mph on a 90-foot-radius curve, and a 0.32 factor at 15 mph on a 50-foot-radius curve. Neither demonstrates a need for a superelevation rate in excess of the normal cross slope.

This data, plus the recognized fact that sharper curves are shorter in length and afford less opportunity for providing superelevation and runout, lead to the derivation of table 1.

TABLE 1. - Recommended superelevation rates, fpf

| Radius of curve, ft | Speed of vehicle, mph | | | | | |
|---|---|---|---|---|---|---|
| | 10 | 15 | 20 | 25 | 30 | 35 and above |
| 50 | 0.04 | 0.04 | | | | |
| 100 | .04 | .04 | 0.04 | | | |
| 150 | .04 | .04 | .04 | 0.05 | | |
| 250 | .04 | .04 | .04 | .04 | 0.06 | |
| 300 | .04 | .04 | .04 | .04 | .05 | 0.06 |
| 600 | .04 | .04 | .04 | .04 | .04 | .05 |
| 1,000 | .04 | .04 | .04 | .04 | .04 | .04 |

This table serves two purposes. It not only suggests superelevation rate rates, but also recommends proper curve and speed relationships. For example, a vehicle traveling 30 mph approaching a 150-foot-radius curve superelevated 0.04 fpf (foot per foot) should slow to at least 20 mph.

## Superelevation Runout

The portion of haulageway used to transform a normal cross-slope section into a superelevated section is considered the runout length. The generally slower speeds at mining sites make the positioning of the runout less critical, but the purpose remains the same--to assist the driver in maneuvering his vehicle through a curve. States vary in their methods of applying superelevation runout. Some apply it entirely on the tangent portion of the haulageway so that full superelevation is reached before entering the curve. Most States, however, apply part on the tangent and part in the curve. For design criteria herein, one-third shall be in the curve and two-thirds on the tangent.

Runout lengths vary with the design speed and the total cross slope change. Recommended rates of cross slope change are shown in table 2.

[5]Work cited in footnote 3.
Meyer, C. F. Route Surveying. International Textbook Co., Scranton, Pa., 1956, 311 pp.

TABLE 2. - Recommended rate of cross-slope change

| Vehicle speed, mph................ | 10 | 15 | 20 | 25 | 30 | 35 and above |
|---|---|---|---|---|---|---|
| Cross slope change in 100-ft length of haulageway (fpf).............. | 0.08 | 0.08 | 0.08 | 0.07 | 0.06 | 0.05 |

To illustrate the use of this table, assume a vehicle is traveling at 35 mph on tangent with normal cross slope 0.04 fpf to the right. It encounters a curve to the left necessitating a superelevation rate of 0.06 fpf to the left. The total cross-slope change required is 0.10 fpf (0.04 + 0.06). The table recommends a 0.05 cross-slope change in 100 feet. Total runout length is computed as 200 feet $[(0.10 \div 0.05) \times 100 = 200]$. One-third of this length should be placed in the curve and two-thirds on the tangent.

## Sharp Curve Design--Widening on Curves

Switchbacks or other areas of haulageways requiring sharp curves must be designed to take into consideration the minimum turning path capability of the vehicles. Figure 17 illustrates the turning radius of vehicles in each weight classification. The radii shown in the accompanying table are the minimum negotiable by all vehicles in each classification. Responsible design dictates that these minimums be exceeded in all except the most severe and restricting conditions. Figure 17 also illustrates the additional roadway width needed by a turning truck. Widths required by vehicles in each weight category vary with the degree of curve. Tables 3 and 4 recommend haulageway widths for curving roadways up to four lanes.

TABLE 3. - Design widths for curving haulageways--single-unit vehicles, feet

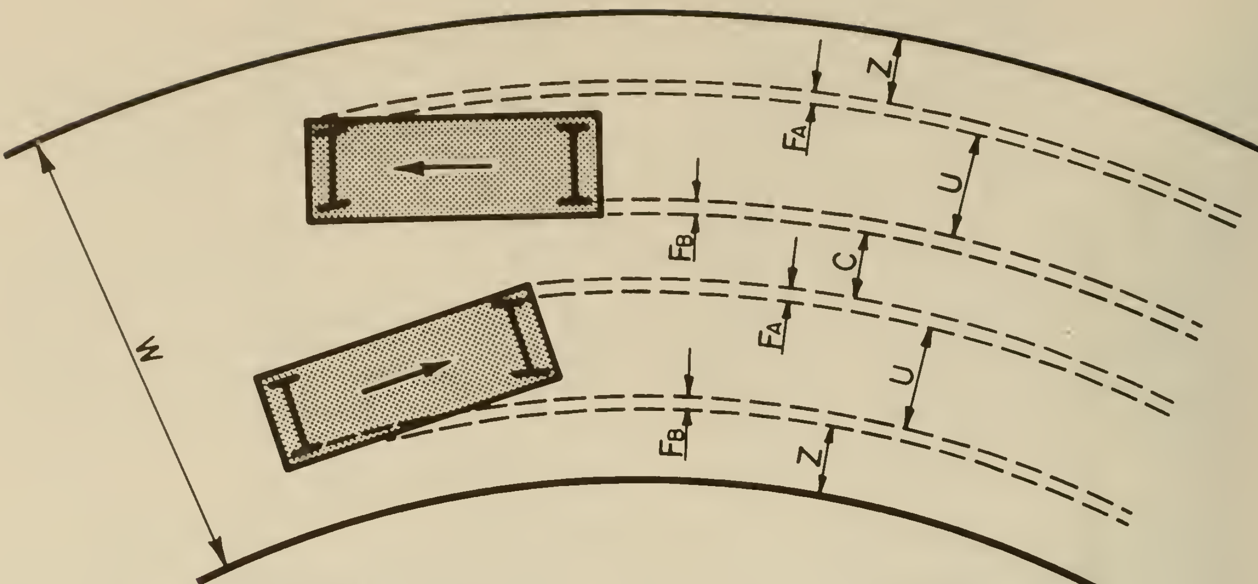
| Curve radius on inner edge of pavement (R), feet | One-lane haulageway, vehicle category-- | | | | Two-lane haulageway, vehicle category-- | | | | Three-lane haulageway, vehicle category-- | | | | Four-lane haulageway, vehicle category-- | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Minimum.................. | 29 | 34 | 45 | 70 | 51 | 60 | 79 | 123 | 73 | 86 | 113 | 176 | 95 | 112 | 147 | 229 |
| 25...................... | 27 | 34 | 44 | 68 | 48 | 60 | 76 | 119 | 68 | 86 | 109 | 170 | 89 | 111 | 142 | 221 |
| 50...................... | 25 | 31 | 41 | 63 | 44 | 54 | 72 | 110 | 63 | 77 | 103 | 158 | 82 | 100 | 134 | 205 |
| 100..................... | 24 | 29 | 39 | 59 | 42 | 51 | 69 | 103 | 60 | 73 | 99 | 147 | 78 | 95 | 128 | 192 |
| 150..................... | 24 | 29 | 39 | 58 | 41 | 50 | 68 | 101 | 59 | 72 | 97 | 145 | 77 | 94 | 126 | 188 |
| 200..................... | 23 | 29 | 38 | 57 | 41 | 50 | 67 | 101 | 59 | 71 | 96 | 144 | 76 | 93 | 125 | 187 |
| Tangent.................. | 23 | 28 | 37 | 56 | 40 | 48 | 65 | 98 | 57 | 69 | 93 | 140 | 74 | 90 | 120 | 182 |

NOTE.--1 indicates category 1 vehicle: <100,000 pounds GVW.
2 indicates category 2 vehicles: 100,000 to 200,000 pounds GVW.
3 indicates category 3 vehicles: >200,000 to 400,000 pounds GVW.
4 indicates category 4 vehicles: >400,000 pounds GVW.

TABLE 4. - Design widths for curving haulageways--articulated vehicles, feet

| Radius on inner edge of pavement (R), feet | One-lane haulageway, vehicle category-- | | | Two-lane haulageway, vehicle category-- | | | Three-lane haulageway, vehicle category-- | | | Four-lane haulageway, vehicle category-- | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 4 |
| 25...................... | 38 | 68 | 86 | 66 | 119 | 151 | 95 | 170 | 215 | 123 | 221 | 280 |
| 50...................... | 32 | 57 | 71 | 56 | 99 | 124 | 80 | 142 | 177 | 105 | 184 | 231 |
| 100..................... | 28 | 48 | 58 | 50 | 83 | 101 | 71 | 119 | 144 | 92 | 154 | 187 |
| 150..................... | 27 | 44 | 52 | 47 | 76 | 91 | 68 | 109 | 130 | 88 | 142 | 168 |
| 200..................... | 26 | 42 | 49 | 46 | 73 | 85 | 66 | 104 | 122 | 85 | 135 | 158 |
| Tangent.................. | 25 | 41 | 41 | 44 | 71 | 72 | 63 | 102 | 103 | 81 | 133 | 133 |

NOTE.--2 indicates category 2 vehicles: 100,000 to 200,000 pounds GVW.
3 indicates category 3 vehicles: >200,000 to 400,000 pounds GVW.
4 indicates category 4 vehicles: >400,000 pounds GVW.




$W = 2(U + F_A + F_B + Z) + C$

$C = Z = (U + F_A + F_B)/2$

U = Track width of vehicle (center-to-center tires), feet
$F_A$ = Width of front overhang, feet
$F_B$ = Width of rear overhang, feet
C = Total lateral clearance
Z = Extra width allowance due to difficulty of driving on curves, feet

| Vehicle Weight Classification | Turning Radius, feet |
|---|---|
| 1 | 19.00 |
| 2 | 24.43 |
| 3 | N A |
| 4 | 38.88 |

FIGURE 17. - Haulageway widths on curves.

### Combination of Horizontal and Vertical Alinement

In the design of haulage roads, it is important that horizontal and vertical alinements complement each other. Poorly designed combinations can accent deficiencies and produce unexpected hazards.

Although the alternatives available to a haulage road designer are limited, it would be prudent to consider the following potential problem conditions.

1. Avoid introducing sharp horizontal curvature at or near the crest of a hill. The driver has difficulty perceiving the curve, especially at night when the lights of his vehicle shine ahead into space. If a curve is absolutely necessary, start it in advance of the vertical curve.

2. Avoid sharp horizontal curves near the bottom of hills or after a long sustained downgrade. Trucks are normally at their highest speed at these locations.

3. If passing is expected, design sections of haulage road with long tangents and constant grades. This is especially important in two-lane operations.

4. Avoid intersections near crest verticals and sharp horizontal curvatures. Intersections should be made as flat as possible. Consider the sight distance in all four quadrants.

## HAULAGE ROAD CROSS SECTION

### Subbase

A stable road base is one of the most important fundamentals of road design. Placement of a road surface over any material that cannot adequately support the weight of traversing traffic will severely hamper vehicular mobility and controllability. Moreover, lack of a sufficiently rigid bearing material beneath the road surface will permit excessive rutting, sinking, and overall deterioration of the traveled way. Thus, a great deal of maintenance will be necessary to keep the road passable.

Surface mine operators often elect to forego the use of subbase materials and accept infringements on mobility in the interest of economics. In other words, it may be less expensive to permit the existence of some segments of the road that hamper, but do not prohibit, vehicular movement, rather than incur the cost of constructing a good road base. Although this appears economical at the onset of road construction, the eventual results will nearly always be undesirable.

If the road surface is not constantly maintained, rutting will occur and create haulage intervals where vehicles must slow their pace to negotiate the adverse conditions. Over a period of time this will represent a considerable time loss to the production cycle. More importantly, these adverse conditions

pose a serious threat to vehicular controllability and create unsafe haulage road segments. Therefore, it is important that stability of the haulageway be guaranteed throughout its length.

In many surface mine operations, the road surface is underlain by natural strata capable of supporting the weight of any haulage vehicle. For example, in the case of bedded stone formations, it is sufficient to place only the desired road surface material directly on the bedded stone. However, the bearing capacity of other subsurface materials must be defined to determine if they can adequately support the weight of vehicles intended for use.

Defining the bearing capacity of soils is a detailed procedure that should be accomplished by a qualified soils engineer. Only in this manner can the capacity of a particular soil be determined. However, general information is available on the bearing capabilities of various soil groups.

The information in table 5, when compared with vehicle tire loads in pounds per square foot, identifies soil types that are inherently stable as road base and those that must be supplemented with additional material. The tire loading for most haulage vehicles filled to design capacity, with tires inflated to recommended pressure, will rarely exceed 16,000 psf. Although the tire loading may be somewhat less, depending on the number of tires, their size, ply rating, and inflation pressure, and overall vehicle weight, this figure can be utilized when determining subbase requirements. Any subgrade that is less consolidated than soft rock will require additional material in order to establish a stable base; therefore, the designer must determine the amount of additional material that should be placed over the subgrade to adequately support the road surface.

TABLE 5. - Presumptive bearing capacity of soils

| Material | 1,000 psf |
|---|---|
| Hard, sound rock | 120 |
| Medium hard rock | 80 |
| Hard pan overlying rock | 24 |
| Compact gravel and boulder-gravel formations; very compact sandy gravel | 20 |
| Soft rock | 16 |
| Loose gravel and sandy gravel; compact sand and gravelly sand; very compact sand--inorganic silt soils | 12 |
| Hard dry consolidated clay | 10 |
| Loose coarse to medium sand; medium compact fine sand | 8 |
| Compact sand-clay soils | 6 |
| Loose fine sand; medium compact sand--inorganic silt soils | 4 |
| Firm or stiff clay | 3 |
| Loose saturated sand clay soils, medium soft clay | 2 |

One of the most widely used methods of making this determination is through the use of curves commonly referred to as CBR (California Bearing Ratio) curves. This system, originally developed in 1942, continues to be used by highway designers for evaluating subbase thickness requirements in

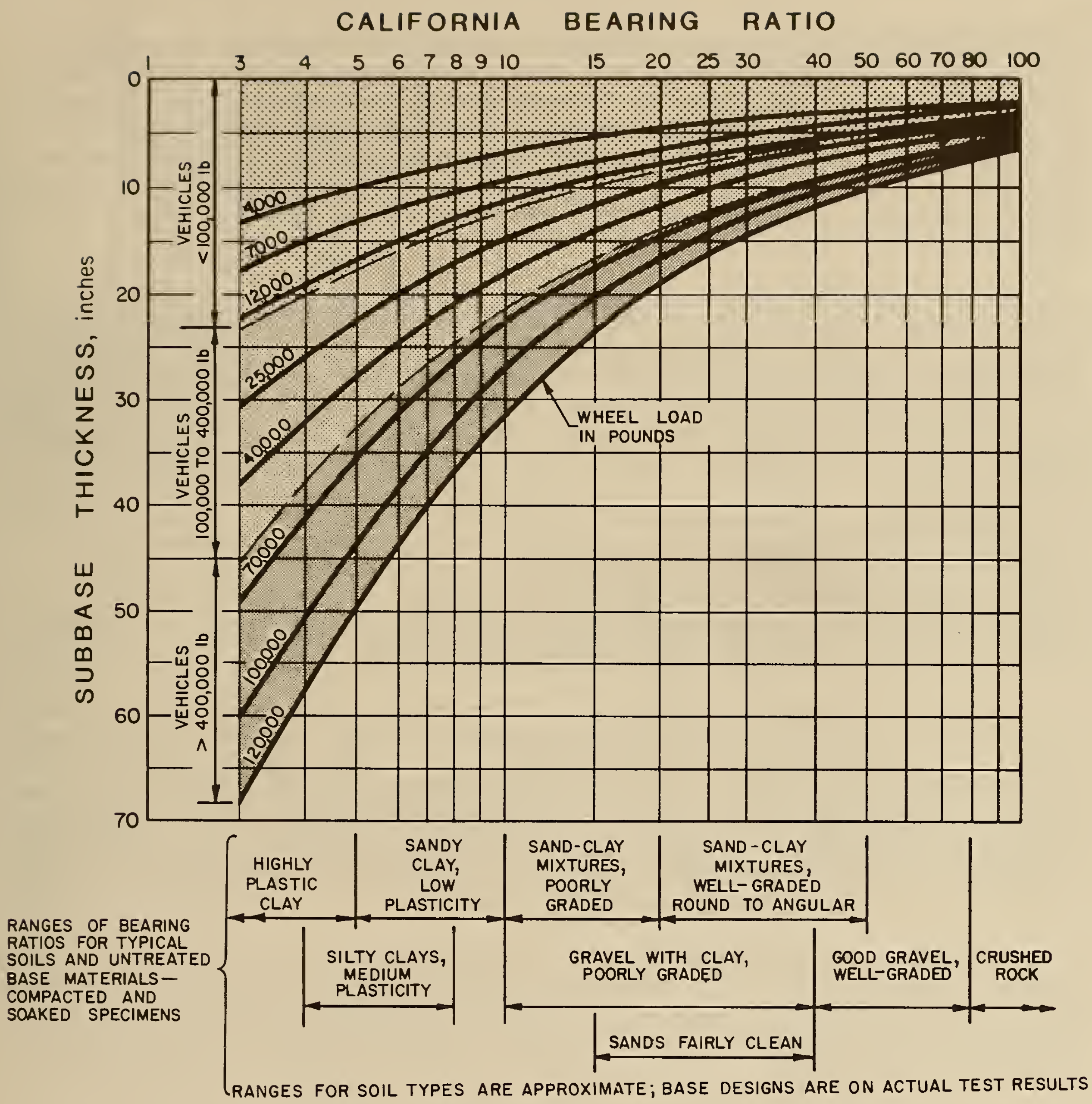



FIGURE 18. - CBR curves.

relation to subgrade characteristics. To be completely accurate, it necessitates CBR tests to precisely determine the bearing capabilities of both subgrade and subbase materials. These tests can be conducted by a soil-testing laboratory at relatively minimal cost simply by submitting samples of the subgrade and subbase materials.

The curves of figure 18 depict subbase thickness requirements for a wide range of CBR test values. To serve as a general indication of the subbase thicknesses required for various subgrade soil types, ranges of bearing ratios

for typical soils and untreated subbase materials are included at the bottom of the graph. It must be emphasized that these ranges are extremely vague. Actual test results may prove the bearing ratios for a specific soil group to be considerably better then the low value depicted on the chart. Although it is not a recommended practice, the CBR ranges reflected by the graph may be utilized in lieu of actual test results if only general information is desired. In this approach, the lowest possible CBR value presented for a given soil type should be used.

As shown by the curves, final subbase thicknesses are determined by vehicle wheel loads as well as soil type. Wheel loadings for any haulage vehicle can be readily computed from manufacturers' specifications. By dividing the loaded vehicle weight over each axle by the number of tires on that axle, the maximum loading for any wheel of the vehicle can be established. In every case, the highest wheel loading should be used for the determinations. When a wheel is mounted on a tandem axle, the value should be increased 20%.

To provide a readily available indication of the wheel-loading characteristics of currently manufactured vehicles, the chart is divided into three categories. Each category represents the range of wheel loadings, under fully loaded conditions, that may be anticipated for vehicles in a given weight class. Classifications do not represent the higher wheel loads that will be incurred by tandem axles in each weight range.

After wheel-loading and CBR values have been established, the chart may be employed to compute subbase requirements, as illustrated by the following example. It must be noted that the graphic plot for any wheel load never reaches zero. This "open" dimension is the depth allocated for the placement of final surface material. When the recommended thicknesses for various surfaces (as prescribed in the Road Surfacing section) fail to consume the open dimension, remaining space must always be filled with a subbase having a CBR of 80 or greater. Crushed rock is preferred.

Example: A haulage road is to be constructed over a silty clay of medium plasticity with a CBR of 5. The maximum wheel load for any vehicle using the road is 40,000 pounds. Fairly clean sand is available with a CBR of 15 to serve as subbase material. Road surface is to be constructed of good gravel which has a CBR of 80.

Step A. The 40,000-pound wheel-load curve intersects the vertical line for a CBR of 5 at 28 inches. This means that the final road surface must be at least this distance above the subgrade.

Step B. A clean sand CBR of 15 intersects the 40,000-pound curve at 14 inches, indicating that the top of this material must be kept 14 inches below road surface.

Step C. An intersection of the 80 CBR for gravel and the 40,000-pound wheel load occurs at 6 inches. Since this will constitute the final surface material, it should be placed for the remaining 6 inches. Completed subbase construction for the foregoing conditions is described in figure 19.

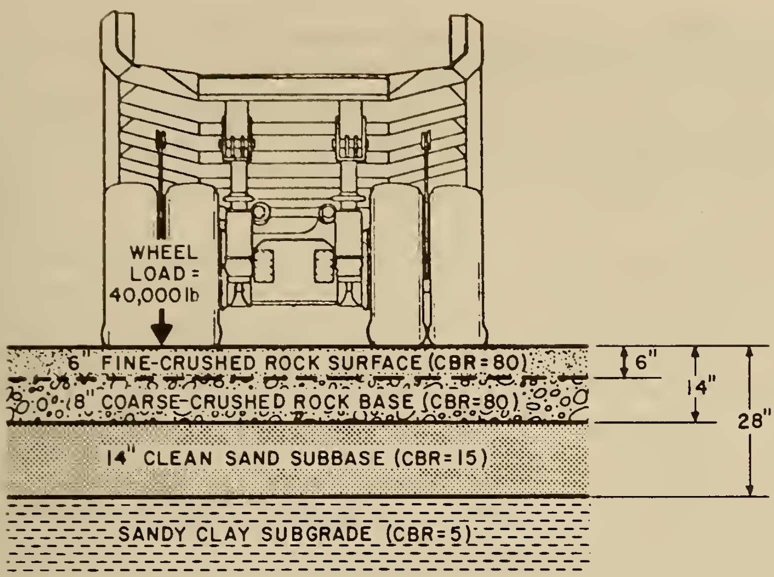



FIGURE 19. - Example of subbase construction.

Following the determination of subbase depth requirements, proper placement procedures must be implemented. Regardless of material used, or depth, the subbase should be compacted in layers never exceeding 8 inches. To insure stability of the final surface, subbase materials should exceed the final desired surface width by a minimum of 2 feet and must always be compacted while moist. Proper compaction equipment usually consists of heavy rollers. However, few surface mine operators include rollers in their vehicle fleet. When rolling equipment is not available, an alternative such as heavy-tracked equipment may be employed. Each 8-inch layer must be subjected to repeated passes of the compacting equipment until it fails to compress under the weight of the vehicle.

## Surface Materials

The authors of this report have visited over 300 mining operations throughout the United States. At many of these mine sites, especially small coal mining and quarry operations, little consideration appeared to be given to the construction of a good haulage road surface. In fact, development of the haulageway is frequently accomplished by simply clearing a path over existing terrain.

While this practice is undoubtedly the most economical means of road construction in terms of initial cost, the benefit is seldom long-lived. Failure to establish a good haulage road surface will result in increased vehicle and road maintenance costs and will severely retard the ability of a vehicle to safely negotiate the route. These difficulties are usually greatest on earth and bedded rock surfaces. Greater vehicle maintenance is required on rock surfaces as a result of excessive tire wear. It is virtually impossible to construct a bedded rock surface free of jagged edges. Thus, the tires of traversing vehicles are continually cut by scuffing.

Earth roads, unless thoroughly compacted and stabilized, may cause both vehicular and road maintenance difficulties. Dust problems are frequent during dry seasons and, if not controlled, the dust can contaminate air filtration components, brakes, and other moving parts, making frequent replacement of these items necessary. Moreover, dust represents a major safety hazard to the vehicle operator in that it can become so dense that visibility is severely reduced. Eliminating the dust problem requires continual wetting of the

surface, which represents yet another maintenance expenditure. When subjected to heavy wetting, nonstabilized earthen roads become extremely slick and severely defaced by erosion. Thus, reduced vehicular controllability from a slippery surface creates a safety hazard, and maintenance must be increased to eliminate erosion gullies. Jagged rock and unconsolidated earth surfaces should always be avoided in a safe haulage road design.

Many of the available road-surfacing materials may be used to maximize safety and reduce road maintenance requirements. However, the field can be narrowed considerably by determining those which are most appropriate for use in haulage road construction. This determination is based on the road adhesion and rolling resistance factors characteristic of different surface types; that is, the resistance factors acting between the road and tire. Road adhesion coefficients play an important role in determining a vehicle's potential to slide. Since the principal concern is haulage road safety, primary emphasis should be placed on these characteristics. Table 6 shows coefficients of road adhesion, determined through years of research, for various surfaces. It must be noted that as the values decrease, the potential for a vehicle tire to begin sliding increases.

A beneficial side effect of selecting a road surface that has a high coefficient of road adhesion for safety is that operational efficiency will increase as well. Rolling resistance has a direct effect on vehicular performance. It is commonly defined as "the combination of forces a vehicle must overcome to move on a specified surface." This factor is usually expressed in pounds of resistance per ton of gross vehicle weight caused by the bearing friction losses resulting from tires sinking in loose material. For the majority of road surface materials, an increase in coefficient of road adhesion can be directly related to a reduction in rolling resistance. Table 7 illustrates this point by presenting the rolling resistance values associated with several road surface materials and their road adhesion characteristics. The data in table 7 indicate that a good road surface will, in many cases, decrease operational costs by reducing resistance to travel. Thus, safety and economics, again, work together.

Asphaltic concrete, crushed stone or gravel, and stabilized earth are the most practical construction materials for developing a haulage road surface that will insure maximum safety and operational efficiency. Because each of these materials has merits that are applicable to specific haulage situations, they are discussed separately in the following pages.

TABLE 6. - Road adhesion coefficients as described by various technical references

| Road surface | Road adhesion coefficients | | | |
|---|---|---|---|---|
| | Rubber tire[1] | Track[1] | Rubber tire[2] | Rubber tire[3] |
| Concrete: | | | | |
| New | 0.90 | 0.45 | 0.80-1.00 | 0.8-0.90 |
| Traveled | | | .60- .80 | |
| Polished | | | .55- .75 | |
| Wet | | | .45- .80 | .80 |
| Asphalt: | | | | |
| New | | | .80-1.00 | .8- .90 |
| Traveled | | | .60- .80 | |
| Polished | | | .55- .75 | |
| Excess tar | | | .50- .60 | |
| Wet | | | .30- .80 | .5- .70 |
| Gravel: | | | | |
| Packed and oiled | | | .55- .85 | .60 |
| Loose | .36 | .50 | .40- .70 | |
| Wet | | | .40- .80 | |
| Rock: | | | | |
| Crushed | | | .55- .75 | |
| Wet | | | .55- .75 | |
| Cinders: | | | | |
| Packed | | | .50- .70 | |
| Wet | | | .65- .75 | |
| Earth: | | | | |
| Firm | .55 | .90 | | .68 |
| Loose | .45 | .60 | | |
| Wet | | | | .55 |
| Clay loam: | | | | |
| Dry | .55 | .90 | | |
| Rutted | .40 | .70 | | |
| Wet | .45 | .70 | | |
| Sand: | | | | |
| Dry | .20 | .30 | | |
| Wet | .40 | .53 | | |
| Coal: Stockpiled | .45 | .60 | | |
| Snow: | | | | |
| Packed | .20 | .25 | .30- .55 | .20 |
| Loose | | | .10- .25 | |
| Wet | | | .30- .60 | |
| Ice: | | | | |
| Smooth | .12 | .12 | .10- .25 | .10 |
| Sleet | | | | .10 |
| Wet | | | .05- .10 | |

[1] Society of Mining Engineers. SME Mining Engineering Handbook. Volume II. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, sec. 17, 1973, p. 70.

[2] Caterpillar Co. Caterpillar Performance Handbook, Peoria, Ill., 1st ed., sec. 19, 1970, p. 42.

[3] Taborek, J. J. Mechanics of Vehicles. Machine Design, Cleveland, Ohio, 1957, p. 8.

TABLE 7. - Rolling resistance for various surface types

| Surface type | Road adhesion coefficient (approx.) | Rolling resistance, pounds per ton gross vehicle weight (approx.) |
|---|---|---|
| Cement, asphalt, soil cement..... | 0.8 | 40 |
| Hard-packed gravel, cinders, or crushed rock................ | .7 | 60 |
| Moderately packed gravel, cinders, or crushed rock........ | .6 | 100 |
| Unmaintained loose earth......... | .5 | 150 |
| Loose gravel and muddy rutted material...................... | .4 | 200-400 |

## Asphaltic Concrete

From a safety standpoint, asphaltic concrete appears the most desirable road surface material. It offers a high coefficient of road adhesion and creates a surface that reduces dust problems. In addition, the characteristic stability of this material creates a smooth haulage surface that can be traveled with little fear of encountering deep ruts of potholes that would impede vehicular controllability. If potholes or ruts do appear, they can be readily corrected by patching.

These surfaces are equally attractive from a production standpoint. While an increasing number of operators are beginning to utilize asphaltic concrete because of lower road maintenance costs, the smooth surface also allows haulage vehicles to travel safely at greater speeds. This speeds up the production cycle.

A seasonal disadvantage to using this composition, however, is revealed during the first snow or freezing rain. The characteristically smooth surface of asphalt offers little resistance to development of an ice or snow glaze. Thus, the roadway can become extremely slick and remain so until corrective measures are employed. This could constitute a serious threat to operational safety in mining areas where rapid and frequent freeze conditions prevail.

If asphaltic concrete is the chosen surface material, it must be applied within the constraints of good engineering practice. In order to be stable, it must be composed of asphalt binder, aggregate, and asphalt cement. The exact mixture for available material in a given locality may be obtained from State Highway Departments or local general paving contractors.

Prior to placing the asphalt, a sufficient subbase must be established, followed by an additional layer of base course. Base course is a term designating the layer of stable material that must lie directly beneath asphaltic concrete. Although any material with a CBR of 80 or greater may be used for this purpose, crushed stone is recommended. Depth of base required will be entirely dependent on subgrade conditions and may be determined with some degree of accuracy by using the curves shown previously in figure 18. The

example given in the figure illustrates that the final clean sand layer of subbase had to remain 14 inches below the final road surface. This is the dimension that must be filled by the combination of base course and asphaltic concrete. Thus, 10 inches of base course and 4 inches of asphalt are required.

Unfortunately, the high cost of asphaltic road surface severely restricts its feasibility on roads of short life. Due to the extreme weight on the wheels of vehicles that constantly travel the haulage road surface, a 4-inch layer may be accepted as the minimum required in most cases. The cost of constructing a 4-inch-thick layer ranges from $4[6] to $5[7] per square yard for labor, equipment, and material. Using the higher figure for a 5-mile road 30 feet wide would necessitate an expenditure of $440,000 for paving alone.

The placement of asphaltic concrete surface is an extremely detailed process that is dependent upon many variables. Temperature of the mix, compaction procedures, wetting, joining, and density control are only a few of the critical elements that must be considered during construction. Unless the mine operator is thoroughly familiar with all elements of asphalt placement or wishes to follow procedures outlined in State Highway Construction Manuals, a reputable paving contractor should be retained to do the work. Before construction of the road, asphaltic concrete should be tested on a small plot to note its adaptability to normal environmental and travel conditions in the area of intended application.

The required base course is also an expense to be considered in the total construction cost. Many operators are capable of performing this operation with their own labor, materials, and equipment, thus minimizing its cost.

Because of the relatively high cost of asphaltic concrete surfaces, each operator must determine if the benefits of increased speed and reduced road maintenance will offset the investment. In most cases, the determining factors will be the length of haul and required life of roadway. If roadway life is relatively short, an asphalt surface may be difficult to justify. If, on the other hand, the haulage road is to be considerably long and in service for a number of years, the placement of asphaltic concrete may be quite feasible.

## Compacted Gravel and Crushed Stone

A great number of surface mining operations throughout the country are presently utilizing gravel and crushed stone surface haulage roads. When constructed and maintained properly, both materials offer a stable roadway that resists deformation and provides a relatively high coefficient of road adhesion with low rolling resistance. The greatest advantage of gravel and stone surfaces is that safe and efficient roadways can be constructed rapidly at a relatively low cost. In areas where the haulage route is subject to

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[6] Robert Snow Means Co., Inc. Building Construction Cost Data for 1975. 1974, 280 pp.

[7] McGraw-Hill Information Systems Co. 1976 Dodge Manual. New York, 1975, 238 pp.

relocation or must accommodate heavy tracked vehicles, it would be impractical to use a permanent surface such as asphaltic concrete.

Determination of the depth of material to be placed follows the same procedure outlined for asphaltic concrete. The depth from surface required for the final subbase material used, as shown in figure 19, determines the thickness of gravel or crushed stone necessary for base and surface.

In some cases, the base and wearing surface may consist of the same type of materials. For example, a crushed stone wearing surface may often overlay a crushed stone base. However, while base materials may consist of particles as great as 4 inches in size, the surface must be much more refined. The following specifications in table 8 present an example of a stone wearing surface that has proven suitable on mine haulage roads. Any crushed stone or gravel that meets or exceeds the specifications presented in the illustration will qualify as an adequate surface composition.

TABLE 8. - Stone surface gradation

| Screen size | Material passing, percent |
|---|---|
| 1-1/2 inches | 100 |
| 1 inch | 98 |
| 3/4 inch | 92 |
| 3/8 inch | 82 |
| No. 4 mesh | 65 |
| No. 10 mesh | 53 |
| No. 40 mesh | 33 |
| No. 200 mesh | 16 |
| Liquid limit | 25.2 |
| Plasticity limit | 15.8 |
| Plasticity index | 9.4 |
| Optimum moisture content during placing | 12.2 |

Bank gravel, which is a mixture of pebbles and sand, frequently exists at many mine sites and thus is usually a low-cost surfacing material. Care should be taken, however, to remove boulders, cobblestones, vegetation, and other undesirable material before the gravel is spread. Other similar materials suitable for surfacing are fine blasted rocks, scoria, disintegrated granite and shale, cinders, volcanic ash, mill tailings, and slag.

The percentage of fines in the gravel will affect surface stability in freezing or hot, dry weather. Therefore, roads that are subject to freezing should not have more than 10% fines to prevent muddy, sloppy conditions when thawing. Those subject to hot, dry weather should not have less than 5% fines in order to prevent drying and loosening.

If proper subbase and base are established prior to placing top material, the depth of surface material need not exceed 6 inches. To achieve a uniform layer, placement should be accomplished with a motor grader or an equivalent piece of equipment. Following placement, the material must be thoroughly compacted to a 6-inch depth. It is recommended that either rubber-tired or steel

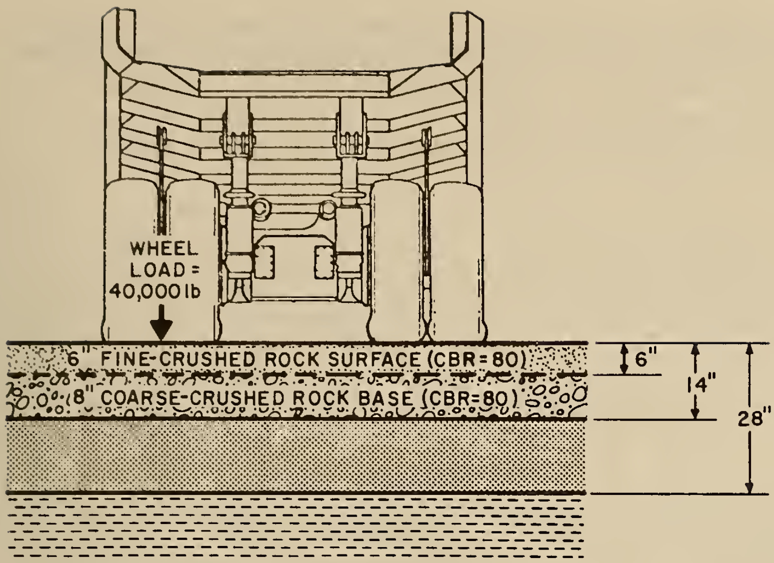


FIGURE 20. - Example of crushed-stone surface construction.

rollers be used for compaction. Heavy rubber-tired vehicles can be employed when rollers are not available. However, rubber-tired vehicles must be run repetitively to cover the entire road width, and compaction will not be quite as good. The following typical section (fig. 20) illustrates a haulage road cross section utilizing a crushed stone wearing surface for a wheel load of 40,000 pounds.

After a haulage surface is constructed with materials of this type, frequent road maintenance is required. Most of this maintenance will consist of periodic grading to remove small ruts and potholes that will inevitably be created by passing traffic. The exact maintenance schedule required will depend greatly on traffic, and it must be developed to accommodate conditions at each individual location. In some cases, traffic may be heavy enough to realize benefits from a continuous maintenance schedule.

In most stone quarry operations, both gravel and crushed stone are readily available from the stockpiles of finished products. At other surface mining operations, crushed stone is often available from the blasting and excavation of rock overburdens. As a result, it is difficult to derive an exact construction cost. However, the expense of constructing gravel or crushed stone roadways is always considerably less than that of asphaltic concrete.

## Stabilized Earth

Stabilized earth is defined herein as any soil that, through special procedures or additives, has been transformed from a naturally unconsolidated state to a degree of stability that will accommodate the weight of haulage vehicles. Achieving this level of stabilization involves incorporating soil binders such as cement, asphalt, calcium chloride, lignosulfates, or hydrated lime.

Although these materials will not create a sufficient haulage road surface, they can significantly reduce the quantity of base material required. In fact, often the various soil binders can be mixed directly with subgrade soils to create a platform for the road surface, making the construction of a subbase unnecessary. At other times soil binders will reduce the amount of subbase or base material required. The potential of a specific binder to reduce or make unnecessary subbase or base material depends on the inherent

strength of the material with which it is to be incorporated and the weight of vehicles that will use the haulage road. Final determinations of feasibility must be made by a qualified soils engineer who has evaluated the effects a binder will have on the subgrade or base material at a particular haulage road location. The application of various additives can be discussed in general terms, however.

Asphalt impregnation and soil cementing, by virtue of their somewhat higher costs, should be utilized primarily for permanent haulage roads. On occasion, they may prove beneficial in areas where the subgrade is extremely weak and would require large quantities of offsite subbase for stabilization. In these instances, the addition of asphalt and portland cement to small quantities of fill material can create a stable base.

Calcium chloride, lignosulfates, and hydrated lime are more economical than asphalt impregnation and soil cement, but are not nearly as effective. These substances are best employed to supplement crushed stone or gravel bases to increase their mechanical stability. Although the construction of any haulage road will benefit from the use of these additives, they are most applicable for road segments that are subject to constant relocation.

If the operator wishes to use any of the materials previously described, two publications[8] may be consulted to determine the type and volume required for a particular situation.

## Haulageway Width

The haulage road designer must be very concerned about the road width. Sufficient room for maneuvering must be allowed at all times to promote safety and maintain continuity in the haulage cycle. Unlike passenger and commercial vehicles which have somewhat "standardized" dimensions, surface mine machinery varies drastically in size from one production capacity rating to another. Thus, requirements have to be defined for particular sizes rather than for general types. Complicating the problem is the need to specify additional widening for straight road to curve transitions.

Because of the large number of influencing variables, the following guidelines for determining width are separated into individual categories. Recommendations presented are values for the size of traveled lane to be provided and do not take into consideration the additional dimensions necessary for subbase outslopes, drainage facilities, berms, etc. These items are discussed separately, and their dimensions must be added to those of the lane to determine the total roadway width.

Width criteria for the traveled lane of a straight haul segment should be based on the widest vehicle in use. Designing for anything less than this

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[8]Portland Cement Association. Soil Cement Construction. Chicago, Ill., 1956, 99 pp.

Wallace, H. A., and J. R. Martin. Asphalt Pavement Engineering. McGraw-Hill Book Co., Inc., New York, 1967, 340 pp.

dimension will create a safety hazard due to lack of proper clearance. In addition, narrow lanes often create an uncomfortable driving environment, resulting in slower traffic, and thereby impeding production.

Rules of thumb for determining haulage road lane dimensions vary considerably from one reference source to another. Many of the guidelines specify a constant width to be added to the width of the haulage vehicle. This method is sufficient for smaller vehicles, but it is not advisable for computing lane spans to accommodate larger machines. To compensate for the increase in perception distance created by greater vehicle width, the space allocated for side clearance should vary with vehicle size.

A practical guideline for establishing the vehicle-to-lane width ratio is contained in the 1965 AASHO Manual for Rural Highway Design.[9] The AASHO Manual recommends that each lane of travel should provide clearance, left and right of the widest vehicle in use, that is equivalent to one-half the vehicle width. Adding credence to this recommendation is the fact that a number of the larger surface mines base their haulageway spans on this criterion. By incorporating this guideline, both safety and efficiency will be enhanced.

Table 9 and figure 21 illustrate the recommended widths that should be provided for various lane configurations based on the design vehicle dimension, along with a typical section depicting how multiple lane dimensions accrue.

TABLE 9. - Recommended lane widths--tangent sections

| Vehicle width, feet | 1 lane | 2 lanes | 3 lanes | 4 lanes |
|---|---|---|---|---|
| 8 | 16 | 28.0 | 40 | 52.0 |
| 9 | 18 | 31.5 | 45 | 58.5 |
| 10 | 20 | 35.0 | 50 | 65.0 |
| 11 | 22 | 38.5 | 55 | 71.5 |
| 12 | 24 | 42.0 | 60 | 78.0 |
| 13 | 26 | 45.5 | 65 | 84.5 |
| 14 | 28 | 49.0 | 70 | 91.0 |
| 15 | 30 | 52.5 | 75 | 97.5 |
| 16 | 32 | 56.0 | 80 | 104.0 |
| 17 | 34 | 59.5 | 85 | 110.5 |
| 18 | 36 | 63.0 | 90 | 117.0 |
| 19 | 38 | 66.5 | 95 | 123.5 |
| 20 | 40 | 70.0 | 100 | 130.0 |
| 21 | 42 | 73.5 | 105 | 136.5 |
| 22 | 44 | 77.0 | 110 | 143.0 |
| 23 | 46 | 80.5 | 115 | 149.5 |
| 24 | 48 | 84.0 | 120 | 156.0 |
| 25 | 50 | 87.5 | 125 | 162.5 |
| 26 | 52 | 91.0 | 130 | 169.0 |
| 27 | 54 | 94.5 | 135 | 175.5 |
| 28 | 56 | 98.0 | 140 | 182.0 |

[9]Work cited in footnote 4.

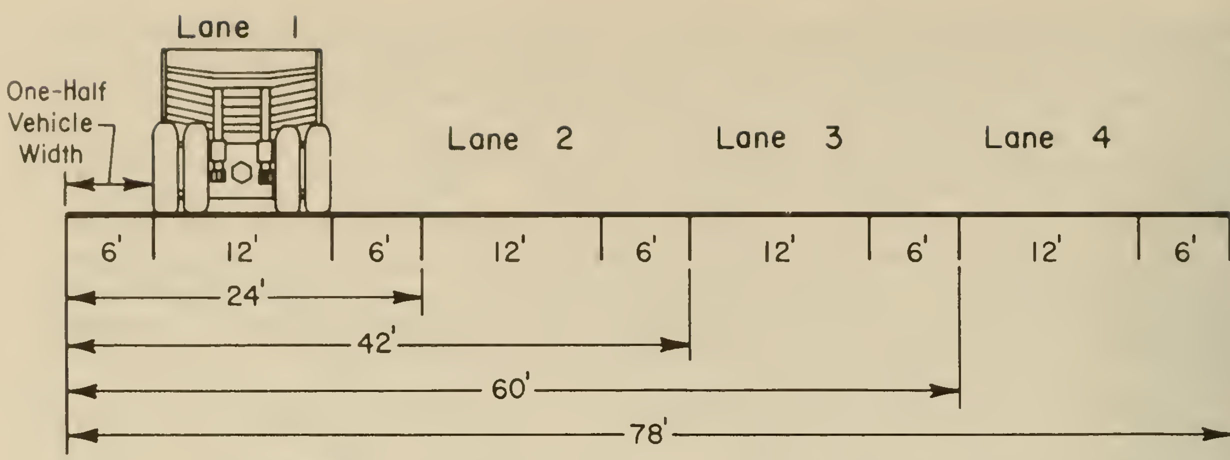


FIGURE 21. - Typical haulageway sections for 12-foot-wide vehicle.

Data presented in this chart is intended to serve as guiding criteria for primary haulage road users. Special consideration must be given to road segments that may have to accommodate larger equipment such as shovels, draglines, drills, etc. A safety hazard will exist if the design road width is less than that necessary for the movement of such equipment. Prior to selecting a final design width, make the following assessments, and establish a dimension sufficient for all possible users:

1. Define the width of all equipment that may have to travel the haulage road.

2. Solicit dimensional data for any anticipated new machines.

3. Determine the overall width of any equipment combinations that may be involved in a passing situation.

4. Delineate the location of road segments requiring a greater than normal width.

In cases where the passage of unusually wide machinery is occasional, there is no reason to establish additional lane width equal to half that of the vehicle. Although in most instances table 9 will serve as an excellent guide for the road designer, there are exceptions for single-lane construction that must be acknowledged.

The lane widths illustrated in the table for one-lane construction apply only when the stopping distance of the haulage vehicle is exceeded by sight distance. On haulage segments where the opposite is true, a single-lane span equivalent to 2-1/2 times the vehicle width is advisable. This will allow sufficient space for moving vehicles to avoid collision with others that might be stalled or otherwise incapacitated on the haulage route. Haulage road planners must also consider the fact that the minimum width recommendations for single-lane roads, even when sight distance is adequate, do not allow sufficient room to pass. If a vehicle should become inoperable on the road, it would restrict the movement of any vehicle equal in size. To prevent this

occurrence, it is recommended that a minimum of 4 feet of additional lane width be provided over the entire haulage route.

## Cross Slope

Cross slope, the difference in elevation between the road edges, must be given consideration during haulage road design and construction. From the standpoint of reducing a driver's steering effort, a level surface would be most beneficial. Adequate drainage, however, requires that a cross slope be created. To accommodate both drainage and steerability, balance must be established between a level and sloped configuration. The rate of cross slope that will allow a rapid removal of surface water without adversely affecting vehicular control must be determined.

Both the theoretical and practical aspects of initiating a constant drop across the breadth of roadways have been studied and documented for years.[10] Although the majority of this work has been conducted in relation to urban and rural highway design, the criteria developed are equally applicable to surface mine haulage roads. In nearly every published reference, the recommended rate of cross slope for surfaces normally constructed on mine haulage roads is a 1/4-inch to 1/2-inch drop for each foot of width.

Mine operators should consider one-quarter to one-half inch per foot as the limiting criteria for design. Special consideration must be given to determining when to use the maximum and minimum rates since the applicability of each depends on surface texture.

Cross slopes of one-quarter inch per foot are applicable to relatively smooth road surfaces that can rapidly dissipate surface water. In most cases, minimum slope is best suited to surfaces such as asphaltic concrete. However, there are conditions which warrant the use of 1/4-ipf criteria for surfaces of lesser quality. When ice or mud are constant problems, excessive cross sloping can cause vehicles to slide. This possibility is especially pronounced at slow operating speeds on grades of more than 5%. Therefore, where an ice or mud problem cannot be feasibly eliminated, cross slopes should be limited to the minimum value. Road maintenance should insure that the road surface is kept smooth and drains properly.

In situations where the surface is relatively rough or where ice or mud is not a problem, a 1/2-ipf cross slope is advisable. The greater inclination permits rapid drainage and reduces the occurrence of puddles and saturated subbase, which can weaken road stability. On well constructed gravel and crushed rock roads, the 1/2-ipf criteria is preferable.

Of equal importance to the degree of slope is the direction it should take in relation to various road configurations. Since the placement of high

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[10] Mudd, S. W. Surface Mining. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, 1968, p. 681.
Word cited in footnote 4.
Seelye, E. E. Design. John Wiley & Sons, New York, 1968, pp. 12-16.

and low lane edges determine slope direction, it is necessary to define the circumstances under which the left edge should be higher than the right or vice versa. In the case of multiple-lane construction, both sides of the final pavement may be equal, with a high point or "crown" at one of the intermediate lane edges.

The cross slope direction for single-lane construction is governed by adjacent land features. In cases where the haulage road is cut into existing ground, the high lane edge may be placed on either side. However, on fill sections, the highest lane edge should be nearest the most severe outslope.

For two-, three-, and four-lane surfaces, a crown is appropriate. On dual- and four-lane roads, the cross slope should be constructed to provide a constant drop at the recommended rate from the center point of the roadway. The location of crown on three-lane haulage roads must insure a continuous drop across two lanes in one direction and the same slope across the other in the opposite direction. The two lanes sloping toward the same edge of road should be lanes for vehicles traveling in the same direction.

## Conventional Parallel Berms

The use of berms has long been accepted as a standard safety feature in areas where a haulage vehicle could accidentally run over the outslope of a haulage road. The applicability and effectiveness of berms were analyzed to establish governing criteria for their design and placement in a typical haulage road operation.

During an exhaustive literature search into similar investigations conducted in the interest of highway safety, many variables were found to govern the response of a vehicle to encountering a berm. Studies have shown the interaction of vehicular dynamics and berm characteristics determine whether a vehicle will impact a berm, deflect off it, or mount and climb over it. All relevant areas of primary research dealt with passenger cars encountering conventional berms at highway speeds. No information was available on vehicles with the characteristics of those normally found in surface mine operations. It is this lack of information in the area of large vehicles that restricted the development of this phase of the project.

The adaptability of available berm information is doubtful in view of the basic differences in vehicle design. Table 10 illustrates the typical relationships between an intermediate size passenger car and large haulage vehicle.

TABLE 10. - Typical vehicle relationships

| | Passenger car | Haulage vehicle | Factor |
|---|---|---|---|
| Weight............pounds.. | 4,000 | 400,000 | 100.0 times greater |
| Wheel base..........feet.. | 9.9 | 19.7 | 2.0 times greater |
| Height of vehicle....do... | 4.5 | 19.0 | 4.2 times greater |
| Wheel track..........do... | 5.0 | 17.0 | 3.4 times greater |
| Rolling radius.......do... | 1.1 | 4.7 | 4.3 times greater |

Using this and other accepted data as a basis for rationalization, various conjectures can be made concerning a haulage vehicle's response to a berm. The enormous weight of a typical haulage vehicle is a major consideration.

The weight would have significant deformational effect upon the berm resulting in a reaction pattern that would be an atypical response to the normal berm cross section. The high center of gravity in combination with a disproportionately narrow width of the wheel track make haulage vehicles more susceptible to overturn than passenger cars. The differences in tire size and steering mechanism reduce the tendency of haulage vehicles to redirect themselves when encountering a berm. Other factors such as inertial characteristics, sprung mass ratio differences, and suspension characteristics indicate significantly different response patterns for haulage vehicles when compared with those of passenger cars.

Assuming that a haulage vehicle would respond in a similar manner to a passenger car in a microscale situation, a proportionally sized berm would be approximately 20 feet high for the average haulage vehicle shown in table 10. It is not possible for such a berm to be economically constructed and efficiently maintained. For a normal berm sideslope of 1.5:1, the additional bench alone necessary to accommodate a berm of this size would be 60 feet.

It was determined from the literature review and analysis that a simplified approach to sizing haulage road berms that does not take into consideration vehicular dynamics would require substantial field testing. An alternative approach would involve an in-depth investigation of haulage vehicle dynamics and a subsequent computerized simulation model analysis. This approach would allow the predictive analysis of a variety of vehicle-and-berm interactions and require only sufficient testing to verify the modeling procedure.

Since the level of endeavor necessary to adequately define the response of a haulage vehicle to a berm is far beyond that originally conceived in the scope of this project, current berm sizing and placement were investigated and documented. This approach allows the standardization of practices that are currently in use, and also permits qualitative discussion of the supporting logic and experience upon which berm rationale has been, and is being, based.

Information gathered during pertinent field investigation provided substantial insight into berm configurations and applications that have met with a degree of success in present haulage operations. In addition, data regarding berms was gathered from Canadian and other international sources.

There are two principal berm designs that are in common use. One is the typical triangular or trapezoidal berm formed typically from unconsolidated, relatively homogeneous material obtained during overburden removal or from material obtained as a result of the haulage road construction itself. The effectiveness of this type of berm in redirecting a vehicle is dependent primarily on the natural angle the berm construction material assumes after being deposited. The steeper the side slope of berm, the more effective the berm is at redirecting the vehicle, all other factors remaining equal. The

inherent tendency of these berms to redirect rather than impact and deflect is a definite advantage in terms of potential vehicle damage in the event of an encounter. It should be emphasized, however, that the redirectional effectiveness of berms is reduced as the angle of incidence is increased, and that this type of berm would tend to overturn the trucks if the wheels continued to climb the berm. Also, maintenance of these berms can be troublesome if the berm material is subject to erosion.

The other most common berm consists of large boulders lining the haulage road with an earthen backing material. This type of berm presents the impacting vehicle with a near-vertical face that deflects the vehicle for slight angles of incidence. Although more difficult to build, this type of berm offers distinct advantages in terms of berm maintenance. The basic limitations imposed by this configuration are (1) substantial damage to the vehicle can result from its use, (2) the vehicle would tend to impact the berm at sharp angles of incidence (possibly injuring the driver), and (3) the local geologic and topographic characteristics of the mining area must accommodate construction of the berm.

Height is the main factor to be considered in designing berms. For conventional berms, the rule of thumb regarding height is that for a berm to possess any measurable tendency to redirect a haulage vehicle, its height must be equal to or greater than the rolling radius of the vehicle's tire. At moderate vehicle speeds, this height allows sufficient time for the driver of the vehicle to apply corrective measures before the truck either overturns or mounts the berm. Additionally, for the natural angle of normal berm-building materials, this height of berm does not require a large amount of additional bench. As a result, it offers basic economic advantages. Berms lesser in height than the rolling radius of the vehicle tire do not allow the driver sufficient response time before the truck mounts and straddles the berm or overruns the berm entirely. Additionally, small berms do not have adequate lateral resistance to effectively assist in redirecting a haulage vehicle.

For boulder-faced berms, the height of the berm should be approximately equal to the height of the tire of the haulage vehicle. This allows an encountering vehicle to impact the berm at a point sufficiently high on the chassis to reduce the potential for overturning, while also improving the deflectional tendencies of the berm as a whole.

The placement of berms on a haulage road must be based on the topographical characteristics of the mining area as well as on common sense. Whenever the potential exists for an accident that could be avoided by the existence of a berm, the initial cost of constructing and extended cost of maintaining a berm is small in comparison to alternative safety features. If the berm is successful once in preventing a potentially serious accident, it has more than paid for itself in relation to the costs of haulage equipment replacement as well as in lost production time.

In summary, the contribution of a berm to the overall safety of a haulage operation depends upon a multitude of factors. A poorly designed or badly maintained berm could conceivably be worse than no berm at all. If a berm is

to be built, the mine operator must consider the purpose for which it would be used, the available materials and technology that can be economically applied to its construction, and its long-term advantages from both a safety and an economic standpoint.

As well as being a safety factor for haulage vehicles, berms serve many other useful purposes; for example, as marking devices for the edge of haulage roads; as drainage channeling devices preventing the uncontrolled erosion of outslopes, as fixed points of reference for haulage vehicle operators, and as effective safety devices for smaller maintenance vehicles that use the haulage road.

## Traffic Signs

Every road in the United States that is publicly maintained uses signs to delineate stopping points, curves, speed limits, street names, intersections, etc. Through years of practical application, these devices have proven to be extremely effective in accident prevention.

The installation of warning and instructional signs can be equally as effective in promoting safety on surface mine haulage roads. However, unlike conventional roads, haulage routes experience traffic from vehicles that are controlled by the same operators day after day. Thus, the drivers are usually thoroughly familiar with all aspects of the roads they travel. As a result, designers can be much more selective in their placement of traffic signs. In the surface mining environment, these safety devices should be viewed as reminders rather than as first warning measures.

A number of signs that should be considered for use along surface mine haulageways are discussed in the following sections.

### Speed Limit Signs

Speed limits should be posted on segments of the haulage route that require slower than normal rates of travel to safely negotiate a hazardous condition. Some of the more advantageous locations for posted speed limit reductions include road segments that precede

1. Changes in descending haulage road grades;

2. Entrances to congested areas, such as pit, crusher, maintenance areas, overburden dumping points, vehicle crossings, etc.;

3. Unusual road alinements, such as severe vertical and horizontal curves, narrow lanes, and areas of restricted sight distance; and

4. Areas subject to material spills or other frequent obstructions.

### Stop Signs

From a production viewpoint, it is best to avoid interruptions in the haulage cycle; however, this may not be compatible with road safety. Although vehicle stopping points along the haulage route should be kept to a minimum, they must be considered necessary for safety in some cases. Areas where the placement of stop signs should definitely be considered are as follows:

1. Any secondary access road at the point it intersects with the main haulageway;

2. Intersections where sight distance does not exceed vehicle stopping distance for the recommended travel rate; and

3. Haulage road intersections with public roads.

### Curve and Intersection Warning Signs

These signs can provide the driver with a warning of upcoming situations where he should exercise caution. These devices are best restricted to positions in advance of the most critical curves and heavily traveled intersections.

### Culvert Crossing Markers

Whenever a culvert headwall or outlet is encountered beside the road, it should be marked with a standing reflector.

### Traffic Control Signs

A sign must be provided at all points in the haulage cycle where the driver is required to perform a special maneuver (Keep Right, One Way, No Left Turn, Do Not Pass, Sound Horn, Blasting--Turn Off 2-Way Radios, etc.).

### Limited Access Designators

Private Property, Keep Out, or other signs of this nature are required at all haulageway and public road intersections to keep passing motorists from inadvertently wandering into the operation. The small size of passenger vehicles combined with the limited sight distance of many large haulage trucks constitutes a safety hazard.

### Safety Access Indicators

The location of all safety features such as escape lanes and median barriers should be signally depicted well in advance of their position. In addition to indicating the immediate entrance to these facilities, distances should be marked along the haulage road at minimum intervals of 250 feet.

The preceding brief discussion of signs is intended to illustrate the traffic signs that should receive primary consideration. Each surface mine

haulage road exhibits its own peculiarities and may require more or less signal definition. In any case, proper care must be taken to insure that all signs installed are at a height and location that is within the eyesight of drivers operating vehicles with the most restricted visibility.

## Drainage Provisions

Soil erosion by water is a common problem that can plague the operation of safe and workable haulage roads. Erosive action on haulage roads can cause ruts and washouts, and can saturate the soil, causing instability. The proper use of drainage facilities can alleviate this problem, resulting in safer, more efficient haulage roads.

### Ditch Configuration and Location

Many factors influence final ditch configuration, including soil type, depth of road base, storm design frequency, local restrictions, percent of grade, and predicted runoff from contributing land areas. However, general recommendations may be made to provide the operator with basic design concepts. V-ditches are recommended for nearly all applications, owing to the relative ease of design, construction, and maintenance.

1. The ditch cross slope adjacent to the haulageway should be 4:1 or flatter except in extreme restrictive conditions. In no case should it exceed a 2:1 slope.

2. The outside ditch slope will vary with the material encountered. In rock it may approach a vertical slope; in less consolidated material, a 2:1 slope or flatter.

3. The ditch should be located in undisturbed earth or rock; avoid placing ditches through fill areas.

4. In a cut-fill section, slope the haulageway toward the highwall. Carry drainage in a single ditch.

5. In a total cut section, carry drainage on both sides.

6. In fill sections, protect the toe of slopes with parallel interceptor ditches.

### Ditch Capacity and Protection

Ditches must be designed to adequately handle expected runoff flows under various slope conditions. The primary consideration is the amount of water that will be intercepted by the ditch during a rainstorm. Various methods to determine runoff flows are described in a separate section.

After runoff flows are calculated, ditch design becomes a function of percent of grade, V-configuration (4:1, 2:1, etc.), and depth of flow. In the V-ditch, as well as other configurations, depth of flow depends on percent of grade and the texture of material lining the ditch. Loose and porous linings

and low percentage grades reduce flow rates and increase depths; smooth, impervious linings and steeper grades create the opposite effect. To alleviate excessive erosion that may result from high flow velocities, certain ditch-lining materials must be incorporated as the grade increases, except when the ditch is in nonerodable material. Some general rules to be followed for various grades in erodable soils are designated below. Please note that these are "general rules" and are by no means recommended to supersede State or local regulations.

1. At a 0% to 3% grade, the ditch may be constructed without benefit of a liner except in extremely erodable material such as sand, or easily weathered shales and silts.

2. At a 3% to 5% grade, the ditch should be seeded and protected with jute matting until a substantial grass lining can be established.

3. At grades over 5%, the lining should consist of dumped rock placed evenly on both sides to a height no less than 0.5 foot above the computed maximum depth.

Following this section are simplified charts that depict the depth of water that may be anticipated in various ditch configurations depending on the contributing flow in cubic feet per second, the percent of grade, and the type of material utilized as a liner. To determine the runoff flow that may be anticipated for a given ditch segment, the operator should first consult his State or local agencies for preferred methodologies to be used in estimating runoff. If no specific guidelines are given by these sources, the necessary information may be obtained from chapter 2 of the Engineering Field Manual for Conservation Practices.[11] This manual outlines the procedures for estimating runoff and contains all the data necessary to compute runoff volumes for all regions of the country.

When utilizing the Soil Conservation Service Engineering Field Manual to develop peak flow rates, the 10-year, 24-hour storm charts should govern. The rainfall intensity generated by a 10-year storm is recognized as the applicable standard for road drainage design by the American Association of State Highway Officials. Moreover, the volumes of water associated with this type of storm are well in excess of normal runoff conditions and necessitate the design of drainage facilities capable of handling extreme, rather than mean, rainfalls.

In the event that a ditch grade must be altered to accommodate changes in topography, the depth of the ditch must be changed accordingly. Whether an increase or decrease in grade occurs, new volumes should be computed based on the flow in the preceding ditch segment and the volume of water generated by the contributing area contiguous to the new grade.

By consulting table 11, the appropriate ditch depth needed to accommodate a specific volume of water may be derived. After determining the slope and finding the waterflow (in cubic feet per second), consult the corresponding ditch configuration table where the cubic feet per second is found. At the extreme left of this line will be the depth necessary to accommodate the flow for that ditch configuration.

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[11] U.S. Department of Agriculture, Soil Conservation Service. Engineering Field Manual for Conservation Practices. 1969, pp. 2-1 to 2-76.

TABLE 11. - Water-volume capacity for various V-ditch configurations, cubic feet per second

| Depth of water (feet) | Slope, percent | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| | Grass cover | | | Jute matting | | | | | Dumped Rock | | | | | | | | | | | |
| 2:1 0:1 | | | | | | | | | | | | | | | | | | | | |
| 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| .4 | .4 | .5 | .6 | .6 | .7 | .5 | .5 | .5 | .6 | .6 | .6 | .7 | .7 | .7 | .8 | .8 | .8 | .8 | .8 | .9 |
| .6 | 1.1 | 1.6 | 1.7 | 1.9 | 2.1 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 2.0 | 2.1 | 2.1 | 2.2 | 2.3 | 2.4 | 2.4 | 2.5 | 2.6 |
| .8 | 2.5 | 3.5 | 3.6 | 4.1 | 4.6 | 3.0 | 3.3 | 3.5 | 3.7 | 3.9 | 4.1 | 4.3 | 4.5 | 4.6 | 4.8 | 4.9 | 5.1 | 5.2 | 5.4 | 5.5 |
| 1.0 | 4.5 | 6.3 | 6.5 | 7.5 | 8.3 | 5.5 | 5.9 | 6.3 | 6.7 | 7.1 | 7.4 | 7.8 | 8.1 | 8.4 | 8.7 | 9.0 | 9.2 | 9.5 | 9.8 | 10.0 |
| 1.2 | 7.3 | 10.3 | 10.5 | 12.1 | 13.6 | 8.9 | 9.6 | 10.3 | 10.9 | 11.5 | 12.1 | 12.6 | 13.1 | 13.6 | 14.1 | 14.5 | 15.0 | 15.4 | 15.9 | 16.3 |
| 1.4 | 11.0 | 15.5 | 15.8 | 18.3 | 20.4 | 13.4 | 14.5 | 15.5 | 16.4 | 17.3 | 18.2 | 19.0 | 19.8 | 20.5 | 21.2 | 21.9 | 22.6 | 23.3 | 23.9 | 24.5 |
| 1.6 | 15.6 | 22.1 | 22.6 | 26.1 | 29.1 | 19.2 | 20.7 | 22.1 | 23.5 | 24.7 | 25.9 | 27.1 | 28.2 | 29.3 | 30.3 | 31.3 | 32.2 | 33.2 | 34.1 | 35.0 |
| 1.8 | 21.4 | 30.3 | 30.9 | 35.7 | 39.9 | 26.2 | 28.3 | 30.3 | 32.1 | 33.8 | 35.5 | 37.1 | 38.6 | 40.0 | 41.4 | 42.8 | 44.1 | 45.4 | 46.6 | 47.8 |
| 2.0 | 28.3 | 40.0 | 40.9 | 47.2 | 52.8 | 34.7 | 37.5 | 40.0 | 42.5 | 44.8 | 47.0 | 49.0 | 51.0 | 53.0 | 54.8 | 56.6 | 58.4 | 60.1 | 61.7 | 63.3 |
| 2:1 2:1 | | | | | | | | | | | | | | | | | | | | |
| 0.2 | 0.1 | 0.2 | 0.2 | 00.2 | 0.2 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 |
| .4 | .8 | 1.1 | 1.1 | 1.3 | 1.5 | 1.0 | 1.0 | 1.1 | 1.2 | 1.2 | 1.3 | 1.4 | 1.4 | 1.5 | 1.5 | 1.6 | 1.6 | 1.7 | 1.7 | 1.7 |
| .6 | 2.3 | 3.3 | 3.3 | 3.8 | 4.3 | 2.8 | 3.0 | 3.3 | 3.4 | 3.6 | 3.8 | 4.0 | 4.1 | 4.3 | 4.5 | 4.6 | 4.7 | 4.9 | 5.0 | 5.1 |
| .8 | 4.9 | 7.0 | 7.1 | 8.2 | 9.2 | 6.1 | 6.5 | 7.0 | 7.4 | 7.8 | 8.2 | 8.6 | 8.9 | 9.3 | 9.6 | 9.9 | 10.2 | 10.5 | 10.8 | 11.1 |
| 1.0 | 9.0 | 12.7 | 12.9 | 14.9 | 16.7 | 11.0 | 11.8 | 12.7 | 13.4 | 14.2 | 14.9 | 15.5 | 16.1 | 16.8 | 17.3 | 17.9 | 18.5 | 19.0 | 19.5 | 20.0 |
| 1.2 | 14.5 | 20.6 | 21.0 | 24.2 | 27.1 | 17.8 | 19.2 | 20.6 | 21.8 | 23.0 | 24.1 | 25.2 | 26.2 | 27.2 | 28.2 | 29.1 | 30.0 | 31.7 | 31.7 | 32.5 |
| 1.4 | 21.9 | 31.0 | 31.6 | 36.5 | 40.9 | 26.9 | 29.0 | 31.0 | 32.9 | 34.7 | 36.4 | 38.0 | 39.5 | 41.0 | 42.5 | 43.9 | 45.2 | 46.5 | 47.8 | 49.0 |
| 1.6 | 31.3 | 44.2 | 45.1 | 52.1 | 58.3 | 38.3 | 41.4 | 44.2 | 46.9 | 49.5 | 51.9 | 54.2 | 56.4 | 58.5 | 60.6 | 62.6 | 64.5 | 66.3 | 68.2 | 69.9 |
| 1.8 | 42.8 | 60.5 | 61.8 | 71.3 | 79.7 | 52.4 | 56.6 | 60.5 | 64.2 | 67.7 | 71.0 | 74.1 | 77.1 | 80.0 | 82.9 | 85.6 | 88.2 | 90.8 | 93.3 | 95.7 |
| 2.0 | 56.6 | 80.1 | 81.7 | 94.4 | 105.5 | 69.4 | 74.9 | 80.1 | 84.9 | 89.5 | 93.9 | 98.1 | 102.1 | 105.9 | 109.7 | 113.3 | 116.7 | 120.1 | 123.4 | 126.6 |
| 4:1 0:1 | | | | | | | | | | | | | | | | | | | | |
| 2.2 | 73.0 | 103.2 | 105.3 | 121.6 | 136.0 | 89.4 | 96.5 | 103.2 | 109.5 | 115.4 | 121.0 | 126.4 | 131.5 | 136.5 | 141.3 | 145.9 | 150.4 | 154.8 | 159.0 | 163.2 |
| 2.4 | 92.0 | 130.1 | 132.7 | 153.3 | 171.4 | 112.6 | 121.7 | 130.1 | 138.0 | 145.4 | 152.5 | 159.3 | 165.8 | 172.1 | 178.1 | 183.9 | 189.6 | 195.1 | 200.4 | 205.7 |
| 2.6 | 113.8 | 160.9 | 164.2 | 189.7 | 212.0 | 139.4 | 150.5 | 160.9 | 170.7 | 179.9 | 188.7 | 197.1 | 205.1 | 212.9 | 220.4 | 227.6 | 234.6 | 241.4 | 248.0 | 254.5 |
| 2.8 | 138.6 | 196.0 | 200.0 | 231.0 | 258.3 | 169.7 | 183.3 | 196.0 | 207.9 | 219.1 | 229.8 | 240.0 | 249.9 | 259.3 | 268.4 | 277.2 | 285.7 | 294.0 | 302.1 | 309.9 |
| 3.0 | 166.5 | 235.5 | 240.3 | 277.5 | 310.3 | 203.9 | 220.3 | 235.5 | 249.8 | 263.3 | 276.1 | 288.4 | 300.2 | 311.5 | 322.4 | 333.0 | 343.3 | 353.2 | 262.9 | 372.3 |
| 3.2 | 197.7 | 279.6 | 285.4 | 329.5 | 368.4 | 242.1 | 261.5 | 279.6 | 296.5 | 312.6 | 327.8 | 342.4 | 356.4 | 369.9 | 382.8 | 395.4 | 407.6 | 419.4 | 430.9 | 442.1 |
| 3.4 | 232.3 | 328.5 | 335.3 | 387.2 | 432.9 | 284.5 | 307.3 | 328.5 | 348.4 | 367.3 | 385.2 | 402.3 | 418.8 | 434.6 | 449.9 | 464.6 | 478.9 | 492.8 | 506.3 | - |
| 3.6 | 270.4 | 382.5 | 390.3 | 450.7 | 503.9 | 331.2 | 357.7 | 382.5 | 405.7 | 427.6 | 448.5 | 468.4 | 487.5 | 505.9 | - | - | - | - | - | - |
| 3.8 | 312.3 | 441.6 | 450.7 | 520.4 | 581.9 | 382.4 | 413.1 | 441.6 | 468.4 | 493.7 | 517.8 | - | - | - | - | - | - | - | - | - |
| 4.0 | 357.9 | 506.2 | 516.6 | 596.5 | 666.9 | 438.4 | 473.5 | 506.2 | - | - | - | - | - | - | - | - | - | - | - | - |
| 4:1 2:1 | | | | | | | | | | | | | | | | | | | | |
| 2.2 | 109.5 | 154.8 | 158.0 | 182.4 | 204.0 | 134.1 | 144.1 | 154.8 | 164.2 | 173.1 | 181.5 | 189.6 | 197.3 | 204.8 | 212.0 | 218.9 | 225.6 | 232.2 | 238.6 | 244.7 |
| 2.4 | 138.0 | 195.1 | 199.1 | 229.9 | 257.1 | 169.0 | 182.5 | 195.1 | 206.9 | 218.1 | 228.8 | 239.0 | 248.7 | 258.1 | 267.2 | 275.9 | 284.4 | 292.7 | 300.7 | 308.5 |
| 2.6 | 170.7 | 241.4 | 246.4 | 284.5 | 318.1 | 209.1 | 225.8 | 241.4 | 256.0 | 269.9 | 283.1 | 295.7 | 307.7 | 319.3 | 330.6 | 341.4 | 351.9 | 362.1 | 372.0 | 381.7 |
| 2.8 | 207.9 | 294.0 | 300.1 | 346.5 | 387.4 | 254.6 | 275.0 | 294.0 | 311.8 | 328.7 | 344.7 | 360.1 | 374.8 | 388.9 | 402.6 | 415.8 | 428.6 | 441.0 | 453.1 | 464.9 |
| 3.0 | 249.8 | 353.2 | 360.5 | 416.3 | 465.4 | 305.9 | 330.4 | 353.2 | 374.7 | 394.9 | 414.2 | 432.6 | 450.3 | 467.3 | 483.7 | 499.5 | - | - | - | - |
| 3.2 | 296.5 | 419.4 | 428.0 | 494.2 | 552.6 | 363.2 | 392.3 | 419.4 | 444.8 | 468.9 | 491.8 | 513.6 | - | - | - | - | - | - | - | - |
| 3.4 | 348.4 | 492.8 | 502.9 | 580.7 | 649.3 | 426.8 | 460.9 | 492.8 | 522.7 | - | - | - | - | - | - | - | - | - | - | - |
| 3.6 | 405.7 | 573.7 | 585.5 | 676.1 | 755.9 | 496.8 | 536.6 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 3.8 | 468.4 | 622.4 | 676.1 | 780.7 | 872.8 | 573.7 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 4.0 | 536.9 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

In some cases, additional depth may be required. In all cases where a subbase must be placed, the depth of the flow must not exceed the lower level of the subbase material. In cases where a freeboard is required, the depth of any ditch shall exceed the centerline depth of flow by a minimum of 0.5 foot. Where placement of a ditch lining material is recommended, it shall also be increased 0.5 foot on each side.

It is important to note that the ditch should be kept free at all times of debris or any material that would alter design capacity.

## Culverts

Culvert sections are the most efficient and effective means of conveying free-flowing drainage away from the haulage road, and must be incorporated to alleviate the potential of water overflows onto haulage road segments. Any accumulation of water on the haulage road can seriously impede vehicular control and promote road degradation.

To achieve the most efficient drainage scheme, the designer must consider culvert location, sizing, placement, and inlet/outlet controls. Numerous factors affect each of these design considerations. Therefore, each parameter is discussed as a separate category on the following pages.

### Location

1. Culverts should be located at all ditch low points unless natural water courses are present.

2. A culvert should be installed at all road intersections and prior to switchback curves on the upgrade beginning of curvature.

3. Whenever a haulage road segment requires a transition from a through-cut to a cut-fill, a culvert should be installed to intercept drainage prior to spilling over an outslope.

4. Culverts should be placed in natural watercourses intersected by the haulage road.

5. In cut-fill sections, culverts may be placed at various intervals along the ditch to intercept drainage and convey it to natural drainways below the fill slope. This procedure can significantly reduce the size of the ditch required by breaking runoff areas into small segments that contribute only to specific ditch segments.

In some instances, culvert intervals will be the designer's option. However, spacing requirements are often specifically delineated in State or local codes of construction practice. A typical example is the regulation imposed by the West Virginia Department of Natural Resources Division of Reclamation.[12]

[12]Department of Natural Resources. West Virginia Surface Mining Reclamation Regulations. Ch. 20-6, ser. VII, sec. 4, No. 5.06, 1971, p. 10.

This agency requires the spacing of culverts for ditch relief at various road grades as noted:

| Road grade, percent | Spacing of culverts, feet |
|---|---|
| 2- 5 | 300-800 |
| 6-10 | 200-300 |
| 11-15 | 100-200 |

The preceding illustration exemplifies the need to research all State or local standards prior to any design decisions. If there are no regulations regarding culvert spacing, the following is recommended:

1. Spacing should not exceed 1,000 feet on grades from zero to 3%.

2. Spacing should not exceed 800 feet on grades from 3% to 6%.

3. Spacing should not exceed 500 feet on grades from 6% to 9%.

4. Spacing should not exceed 300 feet on grades 10% or greater.

Type and Size

For the majority of haulage-road culvert installations, corrugated metal pipe is most appropriate. Since this type of pipe is relatively light, high in strength, and usually readily available, it can be easily adapted to a variety of situations. Although other materials can be utilized, corrugated metal is currently used extensively throughout the surface mining industry.

Regardless of material, the culvert must be able to accept the maximum runoff flow from the drainage ditch to be completely effective. Also, the pipe diameter must be large enough to accept maximum flow without creating a backup at its inlet. Figure 22 may be utilized to determine pipe sizes for various flows. Flows in cubic feet per second on the left side may be read to their intersection with the diagonal graph line and then down to the corresponding minimum pipe diameter necessary to accept the flow. This minimum is indicative of a full flowing pipe without any water backup at the inlet. In some cases, however, it may be desirable to place a smaller, less expensive pipe and allow a small backup of water. The dashed lines on the chart (labeled "H") are included to depict how much head will be created behind the pipe if its size is restrictive. To determine the amount of head created by a given pipe size and cubic feet per second, read from the cubic feet per second column until the dashed line is intersected, then down. For example, a flow of 8 cfs intersects 2 feet of head at the 15-inch pipe diameter, thus 8 cfs of water at the inlet side of a 15-inch pipe will pond 9 inches above the top of the pipe (2 feet minus 15 inches). However, it must be emphasized that the practice of creating an inlet head is discouraged. The most beneficial design requires that a pipe handle the entire volume of water without backup. If the example for cfs were to be followed without creating a backup, the intersection of the diagonal will show that a pipe diameter of approximately 21 inches is required.

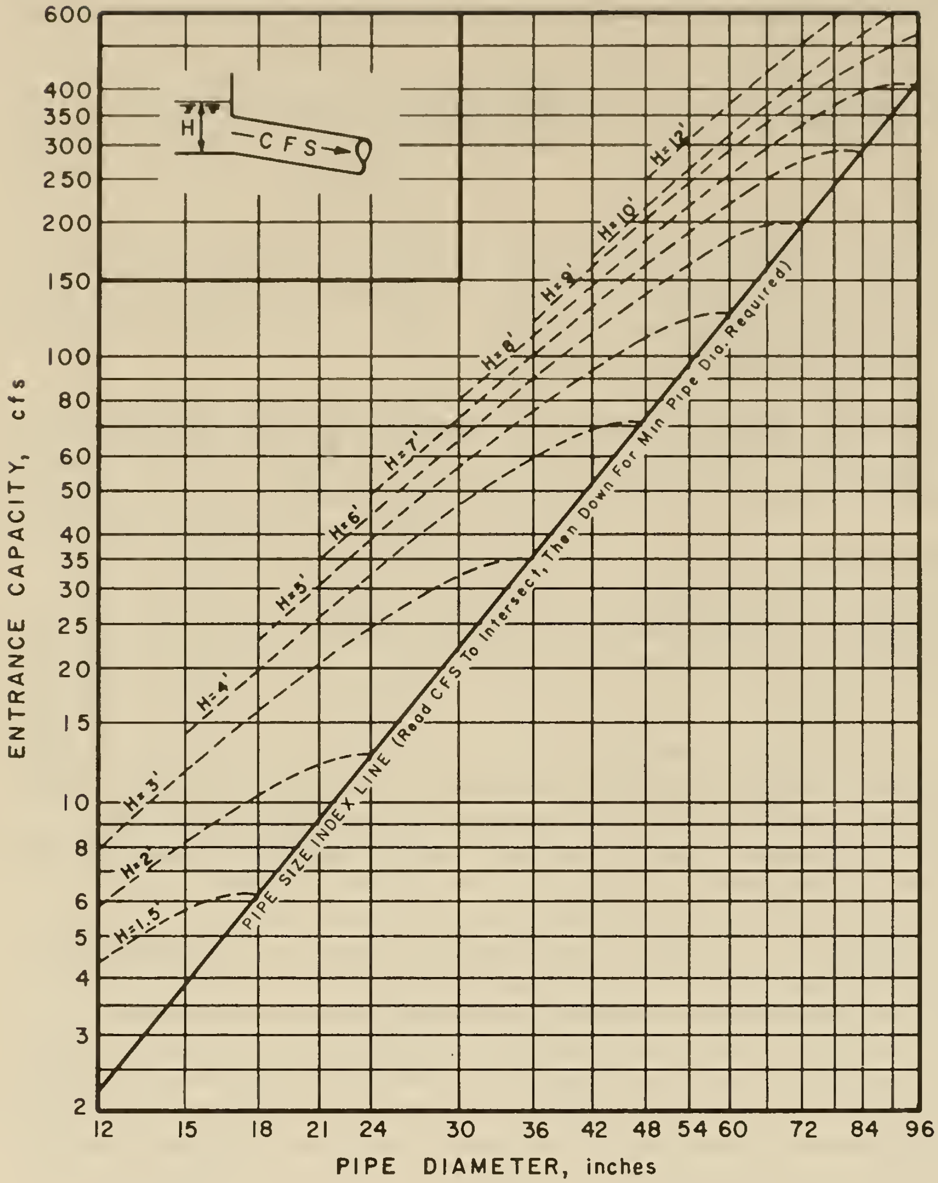



FIGURE 22. - Graph showing pipe culvert capacity.

Placement

After the location and pipe size have been selected and the pipe is ready for placement, consideration must be given to depth of cover over the pipe in relation to the vehicles that will use the road. It is suggested that for support of vehicle weight under 100,000 pounds, a minimum cover of 2 feet over the pipe be used. For support of vehicle weights over 100,000 pounds, minimum cover should be 3 feet.

In all cases, the fill should be hand-tamped in 4-inch layers from the bottom of trench to provide a stable, compacted base for the culvert.

Inlet-Outlet Controls

At all culvert inlets, a protective encasement or "headwall" consisting of a stable nonerodable material should be provided.

Regulations specifying erosion- and sediment-control devices to be utilized at storm drain outlets have been developed by the U.S. Department of Agriculture, Soil Conservation Service. In addition, many States have adopted their own regulations for this purpose. By contacting one or both of these agencies in the region, the operator can determine the requirements that apply specifically to his operation. However, there are two rules of thumb to follow:

1. Flow from ditches or culverts shall never be discharged over a fill outslope. In fill situations, the discharges must be conveyed away by pipes, flumes or ditches lined with nonerodable material.

2. At any discharge point, where flow velocity exceeds the Soil Conservation Service's recommended maximum for various soil types, erosion protection must be provided. Examples are shown in figure 23.

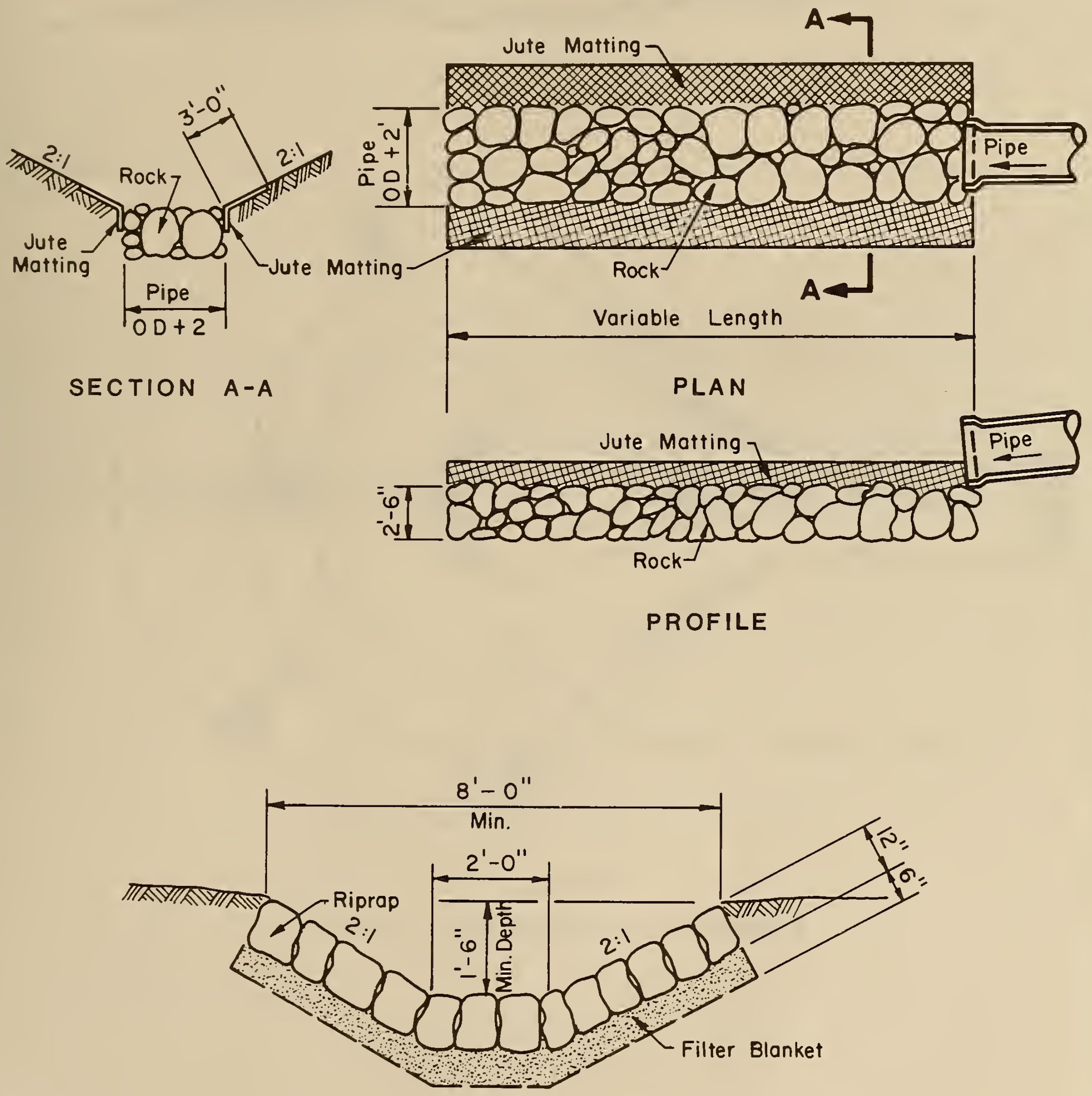
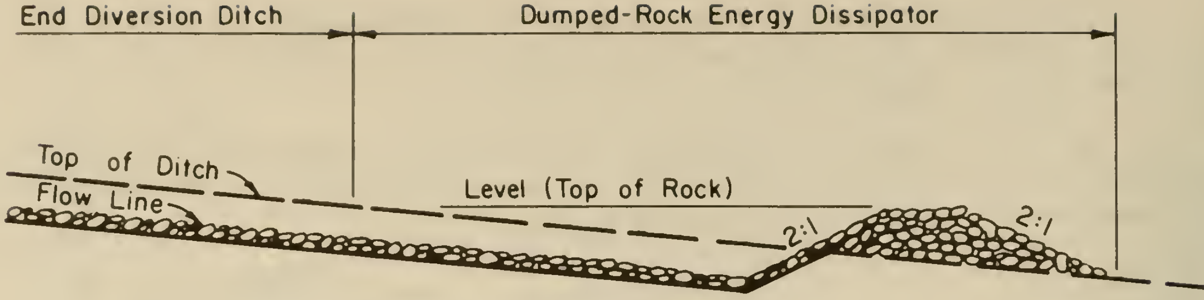
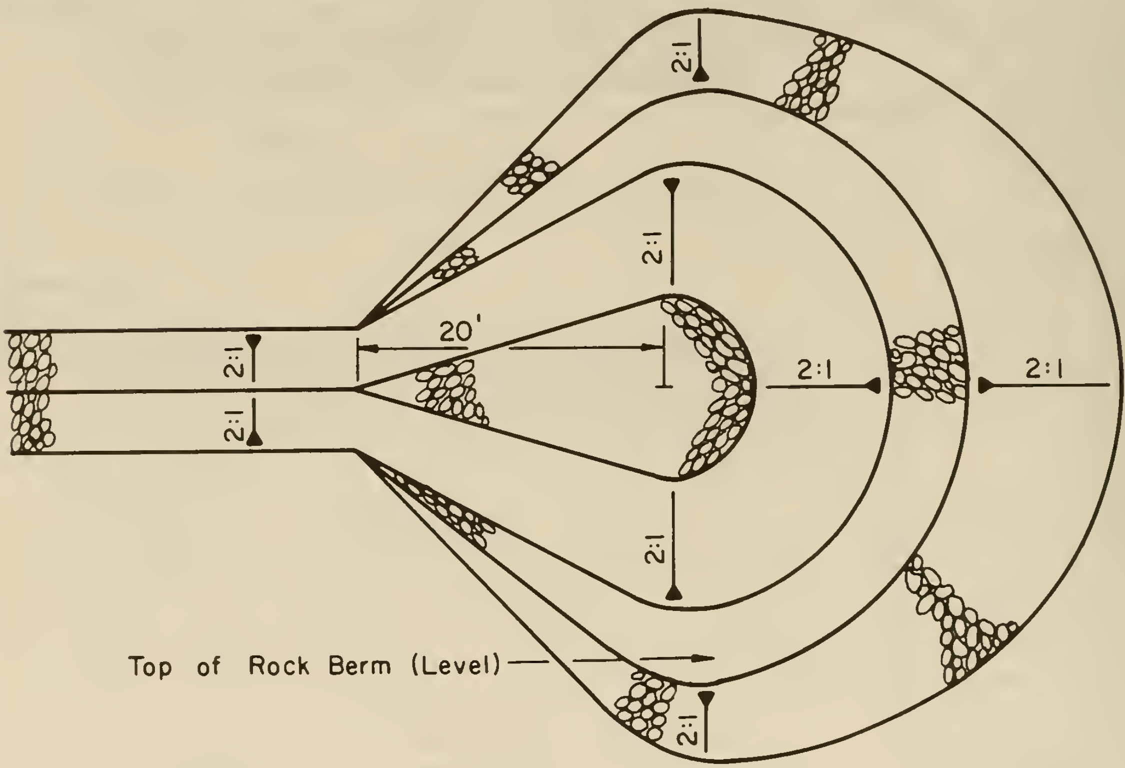



FIGURE 23. - Erosion controls.




PROFILE




PLAN

FIGURE 24. - Dumped-rock energy dissipator.

Table 12 depicts the various treatments that may be anticipated for erosion control dependent on discharge velocity. Details are presented in figure 24 for the riprap and energy dissipator treatment techniques as a guide for proper construction. The lengths of these devices will be entirely dependent on slope lengths and must be determined for each individual situation.

TABLE 12. - Slope protection at culvert outlets

| Outlet velocity, fps | Slope of embankment, percent | Treatment recommended |
|---|---|---|
| 0-2 | Under 10 | Establish vegetation. |
| 2-5 | Over 10 | Riprap. |
| 5-15 | All slopes | Do. |
| Over 15 | .....do | Energy dissipator. |

## Typical Haulageway Sections

All of the criteria for proper haulage road cross-section design are depicted in figure 25: design considerations for a typical cut section, a typical fill section, and a typical cut-fill section. The type of section applicable to any particular haulage road is, of course, dependent upon the contour of the original ground surface. However, figure 25 and the recommendations provided throughout this section of the report as a guide, all of the most important parameters that must be considered during design of cross sections will be covered. Particular attention should be paid to road cross slopes and drainage ditches since these will contribute greatly to good drainage and, therefore, more effective erosion control.

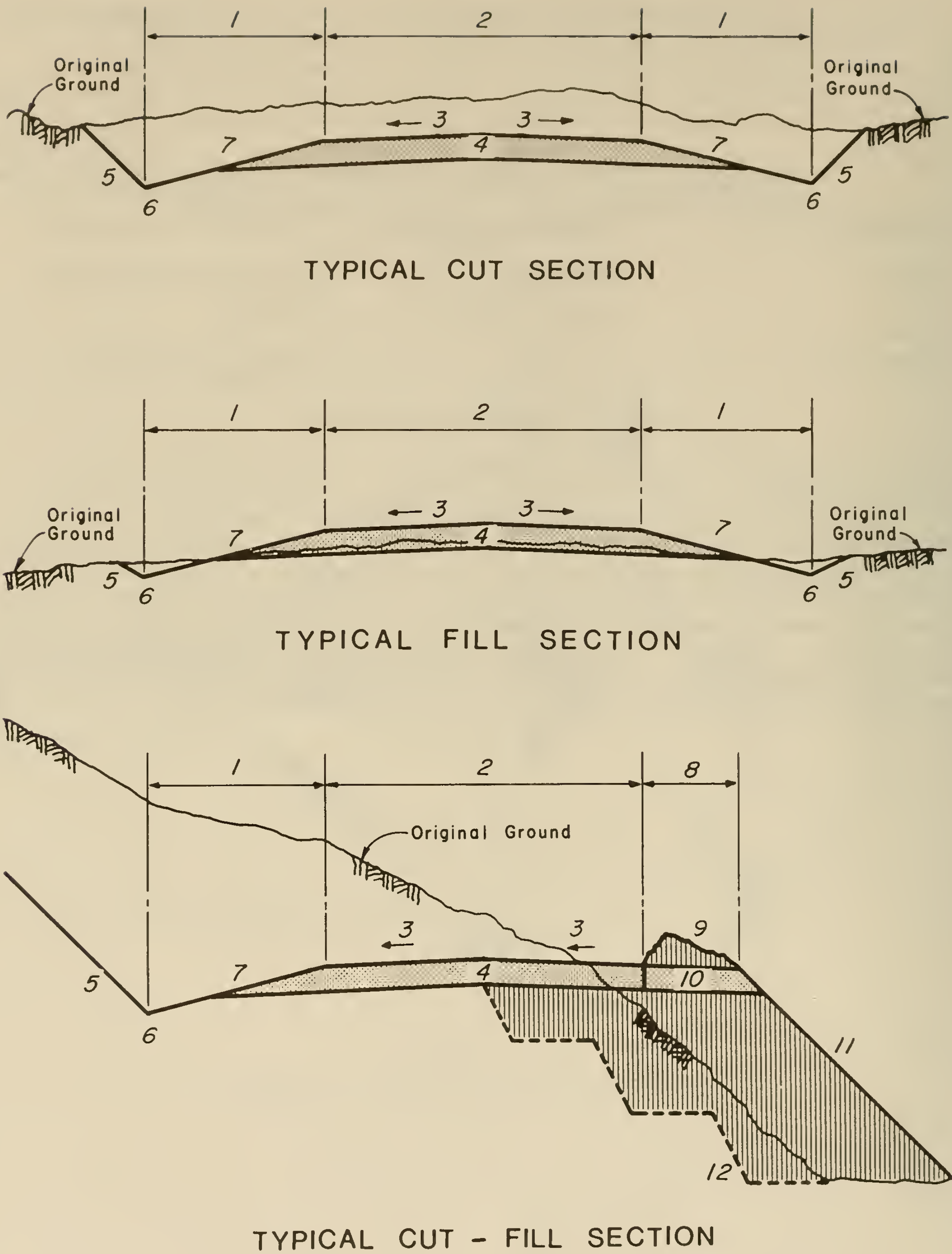



FIGURE 25. - Typical haulageway sections.

Key

*1* - Lane edge to centerline of ditch—Dimension varies with centerline depth *(6)* and required slope *(7)*.

*2* - Lane width—Based on dimension of largest vehicle and numbers of lanes desired.

*3* - Typical cross slope for excavated subgrade and final surface—Either 1/4 or 1/2 ipf, depending on surface material used.

*4* - Combined surface and subbase—Depth varies with wheel load concentration.

*5* - Ditch outslope—Natural angle of repose in rock, 2:1 in all soils.

*6* - Depth at centerline of ditch—Required to be below subbase and deep enough to accept total volume of runoff from adjacent drainage area.

*7* - Ditch slope adjacent to roadway—Varies from 4:1 to 2:1.

*8* - Road widening to accommodate safety berm—Dimension varies with berm size required.

*9* - Safety berm—Constructed with a near vertical slope adjacent to lane edge, final height and outslope of berm depends upon the rolling radius of the largest tires that will traverse the haulage road.

*10* - Berm support—Constructed to subbase material only; surface material ends at berm face.

*11* - Fill slope—Descending at natural angle of repose, fill consists of material cut from existing ground of other excavated material from the mining operation.

*12* - Fill bench—Required when original ground slope is 1:1 or greater, benches should be cut 8 feet—10 feet horizontally with an 8- to 10-foot vertical lift at 1/2:1; begin at toe of original ground slope and continue benching until road subgrade is reached.

## ROAD MAINTENANCE CRITERIA

Regardless of how meticulously a haulage road is planned and constructed, its surface is bound to be deformed by the constant pounding of haulage vehicles. Although deterioration may be controlled to a great extent by the type of surface material employed, the mine operator must still regard a road maintenance schedule as necessary to safety and economics.

Dust, potholes, ruts, depressions, bumps, and other poor surface conditions can and will occur on any road surface. If left uncorrected, they may impede vehicular control and damage haulage machinery.

When a rolling tire encounters a surface scar, there is a tendency to deflect from its normal direction of travel. Thus, the driver is forced to compensate for the abnormality by increasing his steering effort. If surface deformation is too great or if the driver is not aware of it before impact, complete loss of control may result. Often, even though the driver is able to negotiate a surface irregularity by steering, the tendency to overcompensate immediately after the danger has passed could again result in loss of control.

In addition to degrading safety, road deterioration can be costly from a maintenance standpoint. Although surface mining equipment is designed to accept considerable abuse, its life can be increased if rough handling is kept to a minimum. The wear on virtually every component is increased significantly when a vehicle travels rapidly over a rough surface. If the vehicle must constantly brake to negotiate poor areas, unnecessary lining wear occurs as well.

When machinery must operate in dusty areas, the maintenance problems are compounded. Dust may infiltrate brakes, air filters, hydraulic lifts, and other critical components. The abrasive effect of this fine material is apt to result in frequent and costly cleaning or replacement of these items.

Essentially, the items related to deterioration of road surfaces are weather, haulage vehicles consistently following a similar path in the haulage lane, and spillage. Because these factors are definable, road maintenance should begin with an intensive effort to incorporate preventive rather than corrective procedures.

Roadside ditches and culverts should be periodically inspected and cleaned to insure that no obstructions are present. If not cleared, the drainage facilities may overflow in wet weather and cause erosion of the road surface or saturation of subbase materials. Maintenance crews equipped with hand tools or machinery such as dozers, loaders, and scrapers should be deployed at predetermined intervals to see that all ditch flow lines are free of debris.

If heavy haulage vehicles continue to use the same path in their respective haulage lanes, the concentration of load will eventually create ruts or furrows. To prevent this condition, mine operators should encourage drivers to use different areas of the haulage lane.

Spillage of material from overloaded haulage vehicles is a significant problem at many mines. If spillage is not prevented or if the material is allowed to remain on the haulage route, unnecessary bumps or mounds will exist. Therefore, every effort must be made at the loading point to prevent equipment from being heaped beyond the limit that can be held within the containing vessel.

During periods of dry weather, or in consistently dry environments, dust may become a problem, especially on gravel or crushed stone surfaces. To alleviate this situation, water trucks fitted with special sprinkler systems should be employed. If dust problems are severe, the operator should consider applying chemical additives. The incorporation of chloride salts with gravel or crushed stone surfaces will enhance moisture retention and eliminate the need for frequent road wetting.

Adherence to the preventive measures discussed can significantly reduce haulage road maintenance problems. However, they are not a complete solution. Abnormal surface conditions will occur periodically that require additional road maintenance procedures.

On more permanent surfaces such as asphaltic concrete, surface depressions should be corrected with asphaltic patches and either hand-tamped or rolled into place. When severe depressions occur on well-packed gravel surfaces, the surrounding area should be scarified, filled, and recompacted to an even consistency.

A motor grader should be used continually to maintain cross slopes, remove spills, and to fill and smooth surface depressions as they occur. Whenever the motor grader is used, care must be taken to avoid pushing waste into drainage facilities and the protective faces of safety berms. Accumulated material from the procedure should be removed to specially designated areas.

Ice and snow, whenever they occur, must be completely removed from the haulageway using a motor grader or other appropriate equipment. Special attention to the removal of snow and ice is required on asphaltic concrete and other smooth surfaces. The close-knit texture of these materials make them susceptible to rapid glazing in freezing weather. Consequently, they become slick and a definite hazard to vehicle controllability. Measures such as salting or cindering must be implemented immediately under these conditions.

All areas where loose material is employed to increase rolling resistance and vehicle retardation (escape lanes, median berms) should be periodically checked for loose consistency. If these areas become compacted, a bulldozer equipped with scarifying equipment should be used to break the surface.

## VEHICLE MAINTENANCE CRITERIA

Mine haulage costs often represent up to 50% of total mining costs and sometimes as much as 25% of the overall operating, overhead, and other costs

of the entire mining operation.[13] An item of this magnitude deserves, and generally gets, the major share of maintenance attention.

Most mining companies generally provide for regular, extensive maintenance inspections of their haulage vehicles. Some require daily inspection of such things as system pressures and integrity, tire pressure, fluid levels, electrical system continuity, belt tension, etc. Periodic maintenance (daily, weekly, or by hours of operation) is done to replace filters, change oil, grease fittings, clean air filters and breathers, clean and fill batteries, etc. Periodic inspection is required for brake systems pressure, brake linings, wheel bearings, cab controls and accessories, etc. Repair and replacement of components such as engine, transmission, rearend, axle, etc., is performed as required. Many companies require the truck drivers to file daily reports on vehicle condition. An example of a maintenance checklist is shown in the appendix.

During maintenance checks, special attention should be given to all brake system components to see that they are properly adjusted to manfacturer's specifications. A vehicle with improperly maintained service brakes, or pressure leakage in the brake components, which causes activation of the emergency brake system, could result in unequal brake application and excessive heating of one drum. Because ignition of brake system components and flame propagation to other truck areas is not uncommon, fire extinguishers have become standard equipment. In addition, improper adjustment of one or more linings places total dependence on the others. If uncorrected, the brakes that are functioning properly will experience excessive and unnecessary wear.

Although this checklist adequately covers those maintenance items that are to be checked on a 500-hour operating cycle, a daily log should be kept for each piece of equipment. This log book serves to record any difficulties or equipment anomalies experienced by each driver. Items that require repair or adjustment should be noted in the log book for the review of the next driver. If the maintenance item is of sufficient magnitude to affect the operating integrity of the equipment, a notation should be made in the log, and a notification filed with the maintenance foreman. Through this procedure, an operator starting the shift is made aware of the condition of the equipment and can check to see that repairs have been performed. After repairing any equipment malfunctions, the mechanic or electrician performing the work should be required to initial the log entry, and file an independent report to his foreman with a copy to the production foreman, if applicable. At the end of a specified period (1 to 2 weeks), the maintenance foreman should be required to review equipment log books to familiarize himself with minor problems being experienced by the operators. Log pages should be signed, dated, and filed within a master log kept for each piece of equipment.

Any equipment maintenance program must be governed by the individual operation. The foregoing example indicates how the responsibility for equipment maintenance can be distributed to guarantee that adequate checks are conducted

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[13]Burton, A. K. Off-Highway Trucks in the Mining Industry, Part I. Min. Eng., v. 27, 1975, pp. 28-34.

and responsive actions are taken. However, the ultimate responsibility for safe day-to-day operation of haulage equipment depends on the equipment operator. Since any deficiencies will affect safety, the driver should personally insure that his machinery functions properly before beginning work.

Every mining company should initiate a program to educate drivers in the performance of preoperational equipment checks. For most types of haulage equipment, a preoperational check will require no more than 15 to 20 minutes prior to each work shift. The preoperational check of machine components by the driver will be limited to items that are critical to safe operation, and the minimal time expenditure will be compensated by safer vehicle operation.

A general indication of the manner in which a driver's maintenance program can be conducted is delineated by SAE-recommended practice J153. However, the procedures set forth therein do not encompass the numerous component differences inherent to various types of large haulage vehicles. The precise manner in which preoperational checks should be conducted for each equipment type can be established through the manufacturer and maintenance foreman.

Following is a list of items that should be considered essential to an effective preoperational safety check. This list may or may not apply to specific equipment types and is not entirely comprehensive. However, it does illustrate a majority of the primary steps required.

I. Vehicle at rest--parking brakes engaged, wheels blocked

   A. Inspect visible body and chassis components for damage, integrity, and operation where applicable

      1. Windows
      2. Mirrors
      3. Wipers
      4. Lights (brake, parking, service drive, backup, and turn)
      5. Doors (cab and compartment access)
      6. Guards (component shrouds, electric cable insulation, etc.)
      7. Wheels and tires (tread, rock ejectors, lock rings, mounting lugs, and tire pressure)
      8. Steering (control arms and stabilizer bars)
      9. Suspension (shock and spring mounts)
      10. Control lines (hydraulic, pneumatic, mechanical cables, and electric cables)

11. Air tank moisture relief valves

12. Connections at dynamic brake grids

13. Face of engine radiator core

14. Seat and seatbelt mounts

B. Check all accessible reservoirs for proper fluid levels

1. Brake

2. Steering

3. Fuel

4. Radiator

5. Engine lubricant

6. Hydraulic retarder

7. Transmission

8. Batteries

C. Clean cab of all debris and secure tools, fire extinguisher, roadside flares, etc.

II. Engine running, transmission in neutral, parking brake engaged, wheels blocked

A. Inspect visible chassis components for leaks

1. Control lines (hydraulic, pneumatic, and electrical)

2. Air tanks

3. Hydraulic pumps

4. Air compressors

5. Exhaust transfer pipes

6. Coolant lines

7. Radiator(s)

8. Dynamic braking grid blower

B. Check operation of in-cab gages and controls

1. Temperature (oil and water)

2. Pressure (air and hydraulic)

3. Tachometer
4. Airflow-restriction indicators
5. Ammeter
6. Hydraulic servoacutators
7. Accelerator
8. Retarder
9. Service brake
10. Road-condition switch
11. All system engagement indicator lights
12. Steering
13. Horn
14. Backup warning
15. Engine shutdown
16. Emergency engine shutdown
17. Ground fault breaker

III. Vehicle in motion on level surface at low speed

A. Check for proper operation of primary controls

1. Steering
    a. Under power
    b. Engine off to insure integrity of emergency assist
2. Braking
    a. Retarder
    b. Service brakes under power
    c. Service brakes with engine off
3. Transmission

B. Listen for unusual noises

Any component faults detected by the operator during this type of inspection should be noted and reported immediately to the maintenance supervisor. The final determination as to the severity of a detected fault, and whether the equipment is or is not safe to operate, can best be determined by maintenance personnel.

## RUNAWAY-VEHICLE SAFETY PROVISIONS

The large size of haulage vehicles precludes use of conventional vehicle arresting or impact attenuation devices to stop a runaway. In haulage operations with adverse grades, retarder failure has resulted in loss of life and substantial property damage. Some safety provisions should be incorporated into haulage road design to guard against the consequences of runaway vehicles.

The primary design consideration for runaway vehicle protection is the required spacing between protective provisions. If a runaway situation should occur, the driver must encounter a safety provision before his truck is traveling too fast to maneuver. The top speed at which the driver can maintain control (steering) of a particular vehicle is designated "maximum permissible vehicle speed." A single velocity could have been identified as the recommended maximum for all safety-provision entrances. However, the ultimate speed at which a driver can still maintain steerability and guidance of his vehicle varies according to manufacturer's design, road condition, and operator's experience. The speed to accept as a guiding criterion for the spacing of runaway protective devices can best be determined through a cooperative effort between the operators and management at each mine site.

On tables 13 and 14, distances between runaway-truck safety provisions are given for various road grades and maximum permissible velocities or terminal vehicle velocities. They apply to any type of runaway-protection device, and delineate the distance in feet required between safety-measure entrances for a truck to avoid exceeding the maximum permissible vehicle speed.

The tables illustrate differences in spacing requirements as they are affected by initial downgrade speed at the time total brake system failure occurs. Initial truck speed at loss of braking and retardation was assumed to be 20 mph for table 13 and 10 mph for table 14. Although operating speeds may vary considerably depending on policies at each mine, 10- and 20-mph initial velocities constitute a sufficient range for the grades given.

TABLE 13. - Distance between runaway truck safety provisions, feet

(Initial speed at brake failure is 20 mph)

| Equivalent downgrade, percent | Maximum permissible vehicle speed or terminal speed at entrance to safety provision, mph | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 |
| 1.................... | 752 | 1,671 | 2,757 | 4,010 | 5,431 | 7,018 | 8,772 | 10,694 |
| 3.................... | 251 | 557 | 919 | 1,337 | 1,811 | 2,340 | 2,924 | 3,565 |
| 5.................... | 151 | 335 | 552 | 802 | 1,086 | 1,404 | 1,755 | 2,139 |
| 7.................... | 108 | 239 | 394 | 573 | 776 | 1,003 | 1,254 | 1,528 |
| 9.................... | 84 | 186 | 307 | 446 | 604 | 780 | 975 | 1,189 |
| 11.................... | 69 | 152 | 251 | 365 | 494 | 638 | 798 | 973 |
| 13.................... | 58 | 129 | 212 | 309 | 418 | 540 | 675 | 823 |
| 15.................... | 51 | 112 | 184 | 268 | 362 | 468 | 585 | 713 |

NOTE.--Equal to haulage road downgrade (percent divided by 100) minus roadway rolling resistance (pounds per ton).

TABLE 14. - Distance between runaway truck safety provisions, feet

(Initial speed at brake failure is 10 mph)

| Equivalent downgrade, percent | Maximum permissible vehicle speed or terminal speed at entrance to safety provision, mph | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 1.................... | 418 | 1,003 | 1,755 | 2,674 | 3,760 | 5,013 | 6,433 | 8,021 |
| 3.................... | 140 | 335 | 585 | 892 | 1,254 | 1,671 | 2,145 | 2,674 |
| 5.................... | 84 | 201 | 351 | 535 | 752 | 1,003 | 1,287 | 1,604 |
| 7.................... | 60 | 144 | 251 | 382 | 537 | 716 | 919 | 1,146 |
| 9.................... | 47 | 112 | 195 | 297 | 418 | 557 | 715 | 892 |
| 11.................... | 38 | 92 | 160 | 243 | 342 | 456 | 585 | 730 |
| 13.................... | 33 | 78 | 135 | 206 | 290 | 386 | 495 | 617 |
| 15.................... | 28 | 67 | 117 | 179 | 251 | 335 | 429 | 535 |

NOTE.--Equal to haulage road downgrade (percent divided by 100) minus roadway rolling resistance (pounds per ton).

Computation of values was accomplished through the formula

$$S = \frac{\Delta V^2}{2g\ (\sin\theta\ -b)},$$

where $S$ = distance traveled until "maximum permissible vehicle speed" or entrance to runaway truck safety provision is reached, feet;

$\Delta V$ = difference in velocity between travel speed at loss of braking and retardation and the speed of travel at safety provision, feet per second;

$g$ = 32.2 fps$^2$;

$\theta$ = angle of descent, degrees;

and $b$ = coefficient of rolling resistance (expressed as a mean value of 0.05 to encompass the majority of mine road and tire situations), dimensionless.

The following sections discuss two types of runaway vehicle safety provisions. Their spacing should be established in conformance with the recommendations set forth in the preceding discussion.

## Runaway-Vehicle Collision Berms

As research into berms and runaway truck protection progressed within this project, an innovative design from Australia was investigated and found to have considerable merit. Utilizing an intermittent triangular berm constructed in the middle of a haulage road, Australian mining companies have been able to almost eliminate problems with runaway vehicles.

These runaway-vehicle collision berms are constructed of nonconsolidated screened fines and placed at crucial points within the haulage operation. If the brakes and retarder of a vehicle fail during operation, the driver alines the vehicle so that it straddles the collision berms, and rides the vehicle to a stop. This type of median design is actually a simplified form of vehicle-arresting device. The most critical design aspects of this type of berm are the spacing between the berm sections and the height of the berm in relation to the undercarriage of the vehicle. The spacing between berms must be sufficient to allow a runaway vehicle to aline itself with the berm before impact. If properly alined, the vehicle will shear off that portion of the berm above the undercarriage, expending energy through momentum transfer, rolling resistance, and frictional action until stopped. If improperly alined, the vehicle could overturn. Accordingly, adequate space between berms must be maintained to allow the driver time to position his vehicle with respect to the berm.

Typical sections of these berms with sizing and spacing criteria are shown in figures 26 and 27.

A table is provided with figure 26 to show approximate sizing for various tonnage vehicles. Ranges are given rather than specific dimensions since each berm design must be governed by the height of undercarriage and wheel track of the vehicle for which the berm is designed. Where vehicles of different sizes are operating concurrently on a haulage road, the berm should be sized primarily according to the wheel track of the larger vehicle, since smaller vehicles will be stopped on the "entrance ramp" to the berm. The simplicity and economic attractiveness of this design lends itself well to practically any haulage operation. For haulage roads with less severe grades and associated fewer problems with runaway vehicles, collision berms may be located in critical areas only.

A prerequisite to the use of berms is the ability to economically build a road of sufficient width to accommodate them. Another factor is the necessity of using screened fines in the construction. Depending upon the type of operation, a mobile crusher could be used to facilitate the construction and maintenance of the berm.

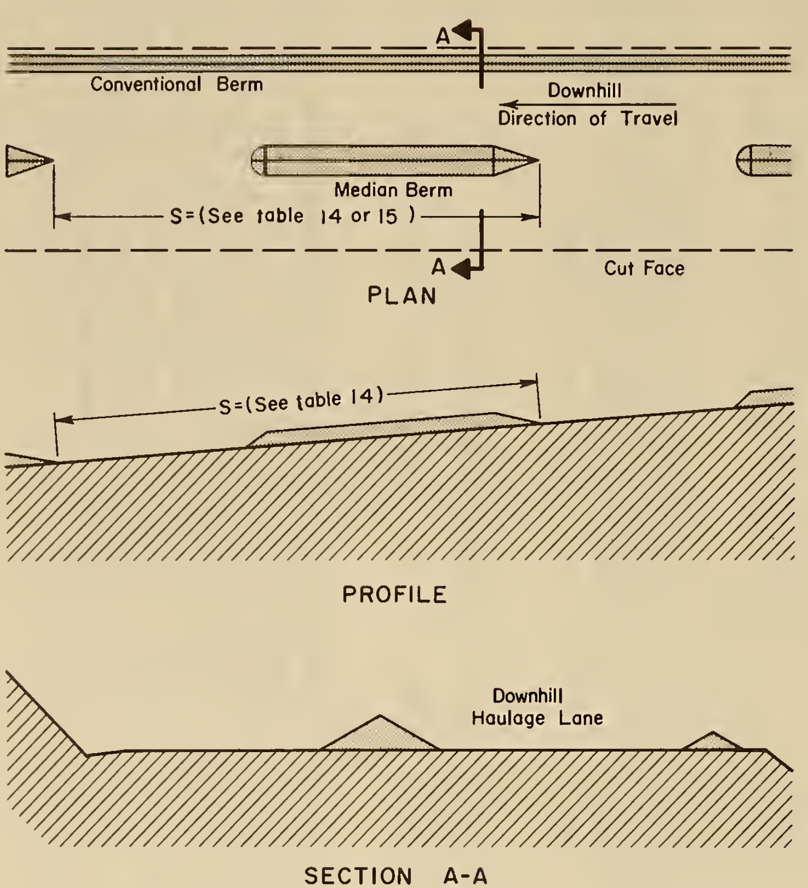
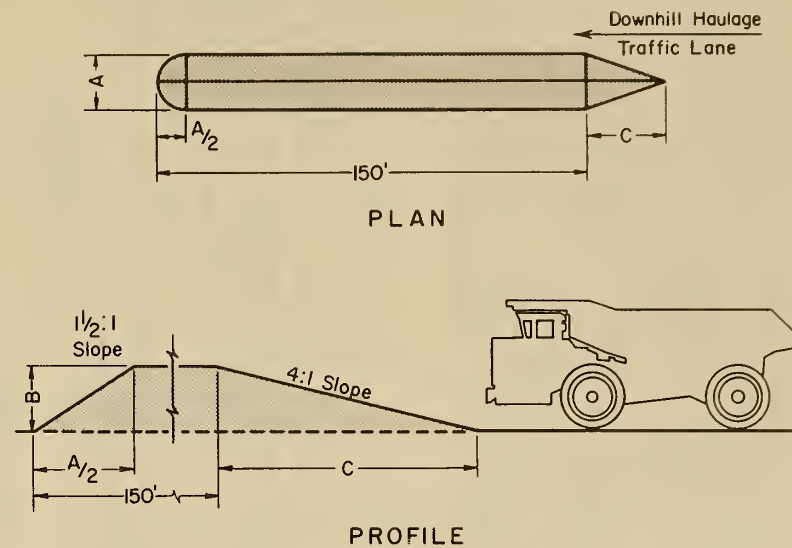



FIGURE 26. - Runaway-vehicle collision berms.




| | A | B | C |
|---|---|---|---|
| CATEGORY 1<br>13 to 25 tons<br>< 100,000 lb | 11'-12' | 3.5'-4' | 14'-16' |
| CATEGORY 2<br>28 to 50 tons<br>100,000-200,000 lb | 12'-15' | 4'-5' | 16'-20' |
| CATEGORY 3<br>55 to 120 tons<br>>200,000-400,000 lb | 15'-18' | 5'-6' | 20'-24' |
| CATEGORY 4<br>120 to 250 tons<br>> 400,000 lb | 18'-32' | 6'-11' | 24'-44' |

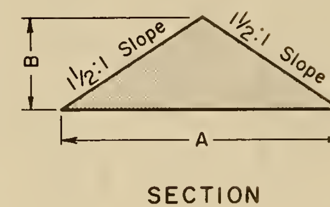



FIGURE 27. - Median application of collision berms.

Median berms are most effective at reduced vehicle velocities. The drivers of haulage vehicles must be instructed in the proper use of the median berm and taught to rely upon it as a first-line emergency maneuver and before the vehicle has accelerated beyond a reasonable speed.

At one mine site in Australia with extremely severe grades (8% to 12%), these median collision berms have been in use for 3 years. Within that time, runaways have occurred on an average of once every 2 to 3 months. In all cases except one, the vehicles were safely stopped with usually only minor damage to the undercarriage. In the one incident where the vehicle was not stopped, the berm slowed the truck to the point where the driver could safely steer into the cut side of the bench.

Prior to incorporating this device in temperate climate areas, careful consideration must be given to required maintenance. The majority of surface-mining States experience freeze conditions during winter months. If collision berms are not protected from solidification in these periods, a vehicle could be severely damaged in an encounter. If climate at the mine site has this potential, collision berms must be constantly checked, and where freezing occurs, the berms must be agitated to achieve their former unconsolidation. In cases where freezing and/or excessive rainfall is a constant problem, a protective covering of material such as polyethylene or an alternate safety provision is recommended.

## Escape Lanes

Escape lanes for control of runaway vehicles have been used extensively on mountain highways in the United States. Relatively simple in design and successful in application, escape lanes are relied upon by highway designers for use on long, sustained grades.

Escape lanes have good potential for intercepting and stopping runaway haulage vehicles. However, they may be expensive to construct and maintain, depending on site conditions. Costs incurred in construction are primarily attributed to bench excavation and roadbed preparation.

Emergency escape lanes have three basic areas of design and construction: entrance areas, deceleration areas, and stopping areas. Each of these will be discussed separately.

### Entrance

The entrance from the main haulageway is perhaps the most important design and construction consideration of an escape lane. Entrance areas must be spaced according to maximum permissible vehicle speed and percent grade of the main haulage road. Included within the entrance area are vertical curve transitions, horizontal curve development (including superelevations), and lane development. Care must be taken that any horizontal curve can be negotiated by the runaway vehicle. Table 15 lists maximum horizontal curves as related to vehicle entrance speeds and superelevations. Superelevations less than 0.06 fpf or greater than 0.10 fpf are not recommended due to difficulties with curve development and drainage.

TABLE 15. - Maximum permissible horizontal curves for escape lane entrance

| Superelevation, feet | Vehicle speed at escape lane entrance, mph | | | | | |
|---|---|---|---|---|---|---|
| | 40 | | 45 | | 50 | |
| | Degrees | Radius, ft | Degrees | Radius, ft | Degrees | Radius, ft |
| 0.06/1............ | 12 | 477 | 10 | 596 | 8 | 716 |
| 0.08/1............ | 13 | 441 | 10 | 578 | 8 | 716 |
| 0.10/1............ | 14 | 409 | 11 | 235 | 9 | 637 |
| | 55 | | 60 | | 65 | |
| | Degrees | Radius, ft | Degrees | Radius, ft | Degrees | Radius, ft |
| 0.06/1............ | 6 | 930 | 5 | 1,146 | 4 | 1,432 |
| 0.08/1............ | 7 | 835 | 6 | 955 | 5 | 1,146 |
| 0.10/1............ | 7 | 796 | 6 | 955 | 5 | 1,146 |

Another important element of proper entrance design is lane width. The lane must be wide enough to accommodate the vehicle but not so wide as to require excessive construction effort. Recommended minimum lane widths for escape lanes are presented in table 16 for various vehicle categories.

TABLE 16. - Recommended escape lane widths

| Vehicle weight, pounds | Minimum width, feet |
|---|---|
| <100,000................... | 15 |
| 100,000 to 200,000......... | 18 |
| >200,000 to 400,000........ | 22 |
| ≥400,000................... | 29 |

## Deceleration

The major contribution of an escape lane to deceleration of a runaway vehicle is that of reverse grade. The greater the reverse grade of an escapeway, the less length required. Table 17 relates escapeway lengths to vehicle entrance velocities and percent grade of the escape lane. The formula used in computing escapeway length is

$$S = \frac{V^2}{2g\ (\sin\theta + b)}, \tag{7}$$

where S = required length of escape lane for deceleration from entrance speed to a full stop, feet;

V = entrance speed from tables 13 and 14, fps;

g = 32.2 fps$^2$;

b = coefficient of rolling resistance, dimensionless;

and $\theta$ = angle of ascent, degrees.

It is important to note that a coefficient of rolling resistance of 0.2 or 400 ppt (pounds per ton) was used to compute the distances. This value is the resistance offered by an unconsolidated surface material such as sand or loose earth. Escape lanes should not be a continuation of the main haulage road, and all normal road maintenance should cease at the end of the entrance area. Escape lanes are most functional when rolling resistance is high. Poorly compacted, deep, loose, granular materials are best suited for roadbed use in deceleration areas since these materials tend to retard vehicle movement. It should also be noted that distances given in table 17 are to be applied from the end of the entrance area; that is, at the end of the horizontal and vertical curves. Also, surface material characteristic of that used on the main haulage road should be employed to the end of these curves.

TABLE 17. - Length of escape lane, feet

| Grade of escape lane, percent | Vehicle speed at entrance to escape lane, mph | | | | |
|---|---|---|---|---|---|
| | 15 | 25 | 35 | 45 | 55 |
| 20 | 19 | 53 | 103 | 170 | 253 |
| 15 | 22 | 60 | 117 | 194 | 289 |
| 10 | 25 | 70 | 137 | 225 | 337 |
| 5 | 30 | 84 | 164 | 271 | 405 |

NOTE.--Assumes coefficient of rolling resistance is 400 ppt or 0.2.

In this manner, a safe transition from hard to loose surface can be achieved.

## Stopping

After a vehicle has been slowed through the deceleration grade and high-rolling-resistance roadbed, it becomes necessary to stop the vehicle and prevent its coasting back down the escape lane. Approximately three-quarters of the way up the escape lane, provisions for stopping the vehicle should begin. Stopping or arresting techniques include the following:

1. A level section of roadway at the end of the escape lane.

2. Median Berm.--A median berm, constructed on the escape lane, is one of the most efficient means for vehicle arrest. Using the same basis for design as that presented in the previous section, median berms are well suited for use in conjunction with escape lanes.

3. Sand or Gravel or Mud Pits.--After a vehicle has been slowed down on the escape lane, a deep sand, gravel, or mud fitted pit will cause the wheels to become stuck, thus prohibiting further movement until assisted by another vehicle. This concept is very effective if properly maintained.

4. Road Bumps.--Road bumps, whether constructed by excavating trenches or establishing mounds across the lane, retard vehicle movement by trapping

in "designed ruts." Mounds or bumps must be thoroughly compacted to insure integrity under the weight of a truck.

5. Manual Steering.--If it is not practical or possible to do any of the foregoing, or if the runaway does not reach the "stopping area," when the truck comes to rest the driver should be trained to either engage the transmission in a "park" position, or set an emergency brake (if usable), or engage the transmission in the lowest possible gear and turn the wheels away from the escape lane berm.

Figures 28-30 depict typical plan, profile, and section views of an emergency escape lane.

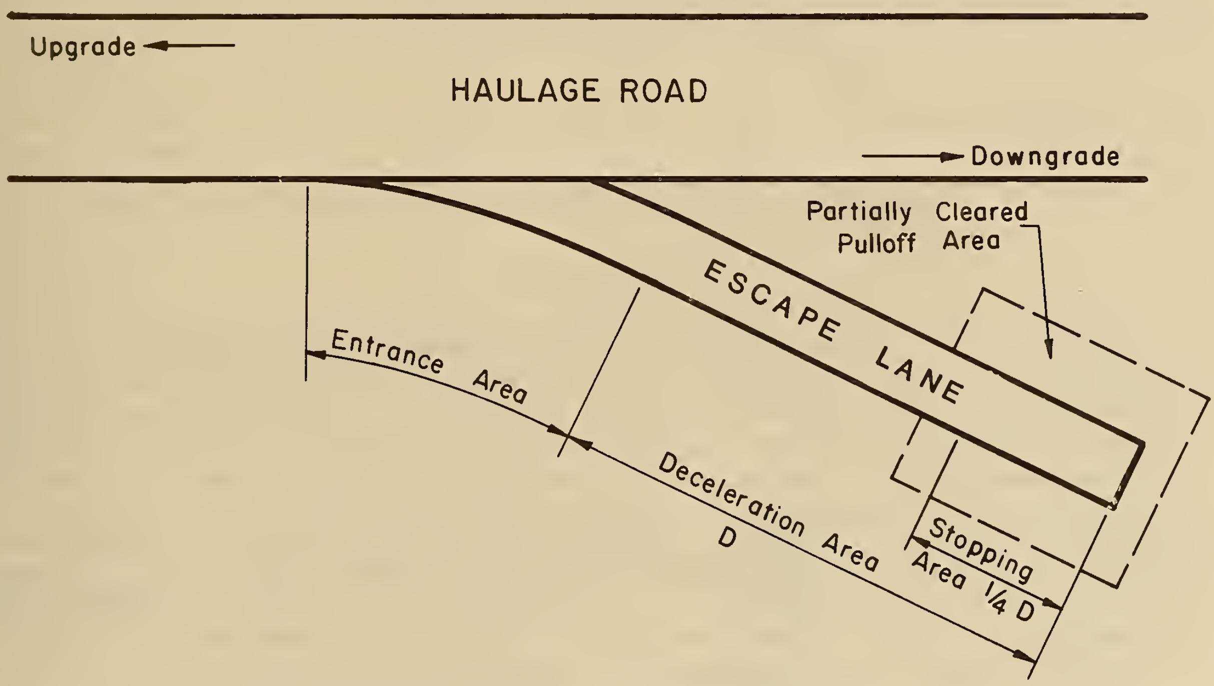



FIGURE 28. - Plan of haulage road escape lane.

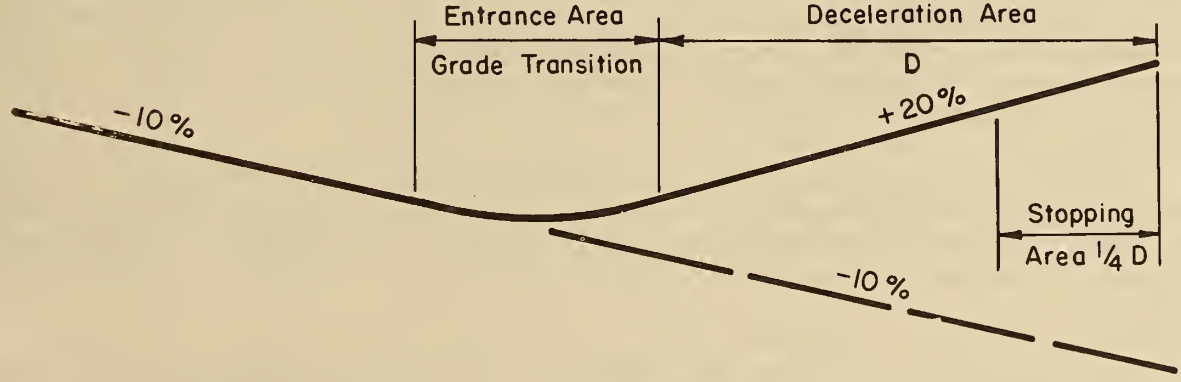



FIGURE 29. - Profile of haulage road escape lane.

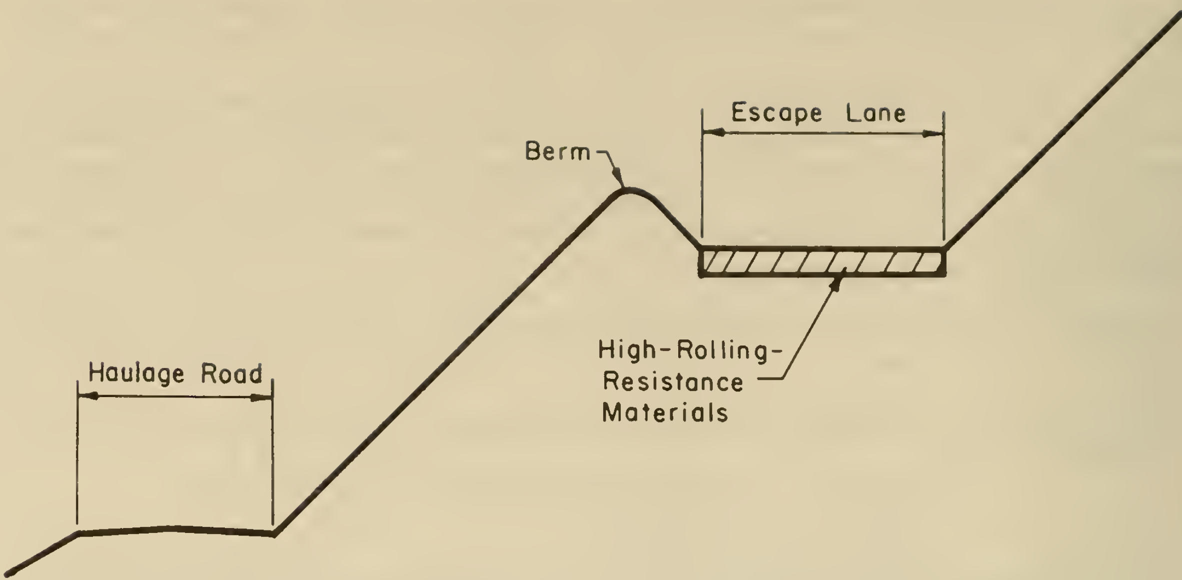



FIGURE 30. - Cross section of haulage road escape lane.

## CONCLUSIONS

Surface mining, regardless of mineral commodity being sought through its inception, is a highly competitive business and, like any other business, a beneficial cost-to-profit ratio must be maintained. It is important to insure that cost efficiency does not impinge upon the intangible aspects of mining such as operator safety and proper equipment utilization. From the sites selected as being representative of typical mining operations, it became apparent that in many instances haulage road construction is not considerate of operator safety; not as a result of disregard, but rather a lack of awareness of correct design principles. The most obvious disparity between existing haulage road construction practices and criteria recommended for safety lies in the areas of alinement and drainage.

Sustained haulage road gradients at many eastern surface mines exceed the 10% maximum stipulated for safety in the Haulage Road Design Study. In most cases, the rationale for constructing a greater gradient is obvious--to keep haulage distances as short as possible through steep mountainous terrain. Superelevation on curves, tangent roadway cross slopes, and vertical curves at grade crests are other design factors seldom applied.

In general, application of adequate roadway drainage provisions are also lacking. Severely scoured and rutted road surfaces, roadside ditches eroded to excessive depths, water-filled depressions in the roadway, and unstable or slippery road segments are common sights throughout the eastern surface-mining region.

As illustrated by table 18, costs associated with haulage road construction to remedy safety hazards such as those mentioned can be considerable. At the surface coal mine sites, for example, construction expenditures exceed $200,000. It must be noted, however, that the haulage roads of each of the

surface coal mines were subjected to major design revisions; thus, costs far exceeded those for the quarry operation where only minor revisions to existing roadway were made. Also, the costs associated with study-site roads were accrued as a result of changes to existing conditions. If the designs recommended herein had been incorporated during construction, the cost of the proposed roadways would have been little more than that of the roadways now being used. Of course, it would be unrealistic to assume that this situation will prevail at all minesites; however, it does apply in a majority of cases.

TABLE 18. - Production-operating-construction cost comparisons

| | Site 1 | | Site 2 | | Site 3 | |
|---|---|---|---|---|---|---|
| PRODUCTION | | | | | | |
| | Existing | Revised | Existing | Revised | Existing | Revised |
| Production per shift per truck......tons.. | 1,480 | 1,520 | 480 | 456 | 2,160 | 2,340 |
| Load (minimum)........ | 4.25 | 4.25 | 5.00 | 5.00 | 2.00 | 2.00 |
| Travel loaded (minimum)............ | 2.90 | 2.65 | 4.88 | 5.43 | 3.43 | 2.57 |
| Dump (minimum)........ | 1.00 | 1.00 | 3.25 | 3.25 | 1.50 | 1.50 |
| Travel empty (minimum)............ | 1.58 | 1.47 | 5.12 | 5.32 | 2.03 | 2.23 |
| Truck capacity..tons.. | 35 | 35 | 20 | 20 | 50 | 50 |
| OPERATING COSTS PER TRUCK PER SHIFT | | | | | | |
| Repair................ | $44.82 | | $24.48 | | $63.54 | |
| Parts................. | 19.26 | | 9.54 | | 27.30 | |
| Fuel.................. | 21.90 | | 16.02 | | 31.68 | |
| Lubrication........... | 6.78 | | 3.96 | | 9.72 | |
| Tires................. | 24.00 | | 13.32 | | 34.80 | |
| Total........... | 116.76 | | 67.32 | | 167.04 | |
| CONSTRUCTION COST OF REDESIGNED HAULAGE ROAD | | | | | | |
| Earthwork............. | $4,800 | | $70,000 | | $90,000 | |
| Road base and surface. | 300 | | 80,000 | | 110,000 | |
| Drainage.............. | 900 | | 120,000 | | 30,000 | |
| Total........... | 6,000 | | 270,000 | | 230,000 | |

The benefits to be derived from safe haulage road design and construction quite often lie unseen as the intangible factors of reduced accidents and injuries. However, in many cases, the incorporation of correct design principles can increase mine productivity. Table 18 illustrates this point for sites 1 and 3. Haulage road revisions at both of these mines will increase haulage rates and, in doing so, reduce operating costs. Moreover, increased haulage road safety will definitely reduce accident potential. If, for example, this increased level of safety prevents one accident that would have destroyed a $150,000, 50-ton haulage truck, road construction costs would be almost offset at the mining operations considered during this study.

Perhaps the most relevant point to be made concerning safe haulage road design is that regardless of site conditions or economics, safety provisions can and must be incorporated. For example, on excessive gradients that cannot be feasibly altered, collision berms or escape lanes can be provided, through

minor earthwork, to arrest runaway vehicles. Little time is required for a dozer to cut roadside ditches and trucks to provide dumped rock where erosion control is necessary. The creation of curve superelevation and tangent cross slope are always possible at little cost. If recommended road-surface materials cannot be obtained, the best materials available can be applied together with a frequent road maintenance schedule to insure consistency and integrity.

24-HOUR MECHANICAL PREVENTIVE MAINTENANCE

| Unit No. | Date | Shift | Hourmeter | Performed By | Supervisor |
|---|---|---|---|---|---|
| | | | | | |

Check all items listed below--repairs to be made during inspection. Major repairs not able to be completed within the 24-hour mechanical preventive maintenance to be written on a shop work order.

| 1. Engine | OK | Repairs made |
|---|---|---|
| A. Fuel system | | |
| Check: Fuel pressure at manifold--65 lb minimum at 1,900 rpm.................... | | |
| Fittings and lines ........ | | |
| For leaks................. | | |
| B. Cooling system | | |
| Check: Radiator and mounting bolts | | |
| Water pump................ | | |
| Fan and belts............. | | |
| Fan hub, mounting bolts and brackets........... | | |
| All hoses and leaks....... | | |
| Fan shroud for cracks..... | | |
| C. Electrical system | | |
| Check: Alt. charging............ | | |
| Batteries................. | | |
| All lights................ | | |
| Rev. alarm................ | | |
| For loose connections ..... | | |
| D. Exhaust system | | |
| Check: Manifolds................ | | |
| Stacks.................... | | |
| Turbos.................... | | |
| E. Air system | | |
| Check: Air tubs, clamp to turbos | | |
| Filters--20 inch maximum at full stall.......... | | |
| Air tanks, front and rear. | | |
| Air box drain tubes...... | | |
| Compressor.............. | | |
| All connections and lines. | | |
| Condition of air cleaner boxes.................. | | |
| F. Oil pressure | | |
| Check: Gage--full rpm no load 40 . | | |
| 60 lb idle 4 to 10 lb ...... | | |
| Engine oil level......... | | |
| For leaks................ | | |
| G. Miscellaneous | | |
| Check: All leaks................ | | |
| Oil, fuel, and water ...... | | |
| Engine mountings front and rear for tightness and cracks................. | | |

| 2. Steering | OK | Repairs made |
|---|---|---|
| Check: Main steering pressure 2,400 psi.............. | | |
| Oil level slave system tank.................. | | |
| Slave steering pressure 500 psi................ | | |
| Steering valve hold down bolts................. | | |
| Steering stops, adjust if necessary 2-3/4 inches.. . | | |
| Steering valve washers... | | |
| Orbitrol valve.......... | | |
| All controls, linkage, cylinders, and bushings.. | | |
| For leaks main steering and slave steering system... | | |
| Emergency steering system................. | | |
| Main hoist pressure 2,200 . | | |

| 3. Brakes | OK | Repairs made |
|---|---|---|
| Check: Brake fluid and breathers.............. | | |
| Lining thickness each wheel--1/4 inch minimum: | | |
| RF.................. | | |
| LF.................. | | |
| RR.................. | | |
| LR.................. | | |
| Brake convertor pressures 1,300 to 1,500 psi minimum | | |
| RF.................. | | |
| LF.................. | | |
| RR.................. | | |
| LR.................. | | |
| Adjust all wheel brakes and parking brake........ | | |
| All lines and fittings.... | | |
| Wheel seals for leaks.... | | |

| 4. Transmission | OK | Repairs made |
|---|---|---|
| Check: Oil level at 800 rpm...... | | |
| Mounting bolts front and rear.................. | | |
| Pressures at 1,000 rpm in each gear.............. | | |
| R................. | | |
| N................. | | |
| 1st............... | | |
| 2nd............... | | |
| 3rd............... | | |
| 4th............... | | |
| For noises............. | | |

| | OK | Repairs made |
|---|---|---|
| **5. Final drive components** | | |
| Check: Differential pinion seals, front and rear for leaks | ☐ | ☐ |
| Differential pinton bearings front and rear for slack | ☐ | ☐ |
| Differential mounting bolts | ☐ | ☐ |
| Planetary carrier bolts | ☐ | ☐ |
| Planetary for leaks | ☐ | ☐ |
| **6. Frame and chassis** | | |
| Check: Articulating hinge pins for slack and lubrication | ☐ | ☐ |
| Frame for cracks | ☐ | ☐ |
| Ride struts--replace if 1 inch from bottoming out (bearings top and bottom of each ride strut) | ☐ | ☐ |
| Rock knockers | ☐ | ☐ |
| Damaged components | ☐ | ☐ |
| Box hinge pins for wear and lubrication | ☐ | ☐ |
| Wishbones and bearings and for lubrication | ☐ | ☐ |
| Mud flaps | ☐ | ☐ |
| Dump box condition .......... good ☐ fair ☐ poor ☐ | | |
| **7. Cab** | | |
| Check: All instruments | ☐ | ☐ |
| Seat | ☐ | ☐ |
| Heater | ☐ | ☐ |
| Glass and mirrors | ☐ | ☐ |
| Window and door components | ☐ | ☐ |
| Windshield wipers and washers | ☐ | ☐ |
| Lockout bolt 5th and 6th gear | ☐ | ☐ |
| **8. Miscellaneous items** | | |
| Check: Wheel lugs | ☐ | ☐ |
| Auto, lub., lines, fittings | ☐ | ☐ |
| Engine output bearing and center driveline bearing | ☐ | ☐ |
| Top driveline bolts | ☐ | ☐ |
| Rear driveline bolts | ☐ | ☐ |
| Front driveline bolts | ☐ | ☐ |
| Interaxle lockup | ☐ | ☐ |
| Torque conv. lockup | ☐ | ☐ |
| Body kickout | ☐ | ☐ |
| Bed pads | ☐ | ☐ |
| Condition of hyd tank | ☐ | ☐ |
| Condition of fuel tank | ☐ | ☐ |
| Bumper footstep, handrail catwalk | ☐ | ☐ |
| Tow cable | ☐ | ☐ |
| Hood condition | ☐ | ☐ |
| Check interlock timer | ☐ | ☐ |

Remarks: ____________________________________________

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